A REPORT and COMMENTARY

on a Series of Cases of

SPONDYLOLISTHESIS

presented in competition for the Pattison Prize in Clinical Surgery and the Robert Jones Prize in Orthopaedic Surgery

by

Alta F. Frances Thompson.
Muir Hall, George Sq.

June 1935.

CONTENTS.

PREFACE.

While "junioring" in one of the surgical wards I was struck by the number of patients who came up for advice, complaining of low back pain. Some had had accidents - miners who had had a fall of coal on to the back; some had gradually developed a pain from no apparent cause.

Out of this number three were diagnosed as cases of Spondylolisthesis. Shortly after this another case was accidentally discovered while making a thorough examination of a patient complaining of epigastric pain. He had no low back pain, and yet showed the typical signs of spondylolisthesis, which diagnosis was clinched after taking an X-ray photograph of the lumbar-sacral region.

I then discovered a very advanced degree of spondylolisthesis in a woman in the Simpson Maternity Hospital. She also had no symptoms of the condition, yet her 5th lumbar vertebra had slipped right off the sacrum into the pelvis, carrying the vertebral column with it.

Having seen these cases, with amazingly different degrees of spondylolisthesis, and equally different degrees of pain and other symptoms, I decided to investigate further into the condition and study the

various forms of treatment that might relieve the symptoms.

I examined numerous X-ray photographs taken in infants for other diseases, but could find no evidence of early cases of spondylolisthesis. The youngest case - a boy of 11 showing a small degree of slipping of the 5th lumbar vertebra - was found by accident, the patient having been X-rayed for another cause. In children no treatment is advised other than teaching the child how to hold himself properly and walk correctly, as growth in all the structures concerned is still taking place. In adults, however, considerable relief can be obtained by operative measures.

I chose the following six cases because they all show different degrees of spondylolisthesis. Some reported with definite symptoms and signs; others were discovered to be spondylolisthetics with no complaint whatever, and various methods were used in treating them.

I am deeply indebted to Professor John Fraser, Professor Johnstone, Mr Walter Mercer and Mr W. Cochrane for their kindness in allowing me to make use of these cases for the purpose of this commentary.

CASE I.

Miss M. I., aged 31, admitted 3.1.34 complaining of pain in the back of five to six years' duration.

History.-

About five or six years ago the patient first felt pain in her back, in the lumbar region. Since then it has become progressively worse. She does not know of any injury or accident which might have caused the pain. She has had treatment for "sciatica" but with little success.

She has a constant feeling of weakness in the low back region, and gets easily tired if she does much standing. The pain is worse after walking any distance, and she has difficulty in rising after bending down. Rest in the supine position relieves the pain.

Apart from her back pain the patient is in good health, according to herself.

The pain is worse during menstruation but is always more of a dull ache than an acute pain.

Previous Illnesses.-

None.

Physical Examination.-

The patient is a sallow, unhealthy-looking woman, tending to stoutness.

Fig.1.
Antero-posterior X-ray showing the typical bow-like outline formed by the transverse processes and body of the 5th.L.v. superimposed on the sacrum.

She has severe acne all over her face, spreading down over her chest and back.

Her tongue is furred and her teeth are bad.

Local Examination.-

Inspection: Standing in the erect position, the patient holds herself well and there is no deviation of the spine. There is slight furrowing over the vertebral column above the 5th lumbar vertebra, but this is not abnormal in any way. There is no creasing horizontally round the trunk between the ribs and the iliac crests.

The abdomen tends to be prominent, but is in no degree pendulous.

Palpation: There is no tenderness elicited over the spinous processes of any of the lumbar vertebrae. Over both sacro-iliac joints there is slight tenderness on deep palpation; this is worse on the left side.

Movements: Flexion limited: hyperextension and lateral flexion good: rotation good.

X-ray Examination.-

Antero-posterior view: The typical bow-like outline formed by the transverse processes and body of the 5th lumbar vertebra superimposed on the sacrum is well marked. There is some degree of upward tilting

Fig. 2.

The 5th. L.v. carrying with it the rest of the vertebral column can be seen slipping anteriorly off the upper border of the sacrum. Slight buttressing of the sacrum has taken place.

of the spinous process and transverse processes of the 5th lumbar vertebra. The marked decrease in density of the shadow of the neural arches of the 5th lumbar vertebra point to a rarefaction or lack of continuity in the bone at this point.

Lateral View: The shadows of the pelvic bones somewhat obscure the region under examination.

The 5th lumbar vertebra can be seen slipping forward off the vertebral surface of the sacrum, carrying the rest of the spinal column with it. Comparing the neural arch of the 5th lumbar vertebra with that of the 4th and 3rd lumbar vertebrae, there seems to be some decrease in the density of the shadow.

A slight degree of buttressing can be made out on the anterior surface of the sacrum, shown by an increase in the density of the shadow.

All other systems.- Nothing abnormal can be detected.

Operation, 8.1.34.

Anaesthetic: Chloroform and ether.

The abdomen was opened through a mid line incision. The foot of the operating table was raised to enable the bowel to be more easily packed out of the way, in an upward direction.

The peritoneum on the posterior abdominal wall was

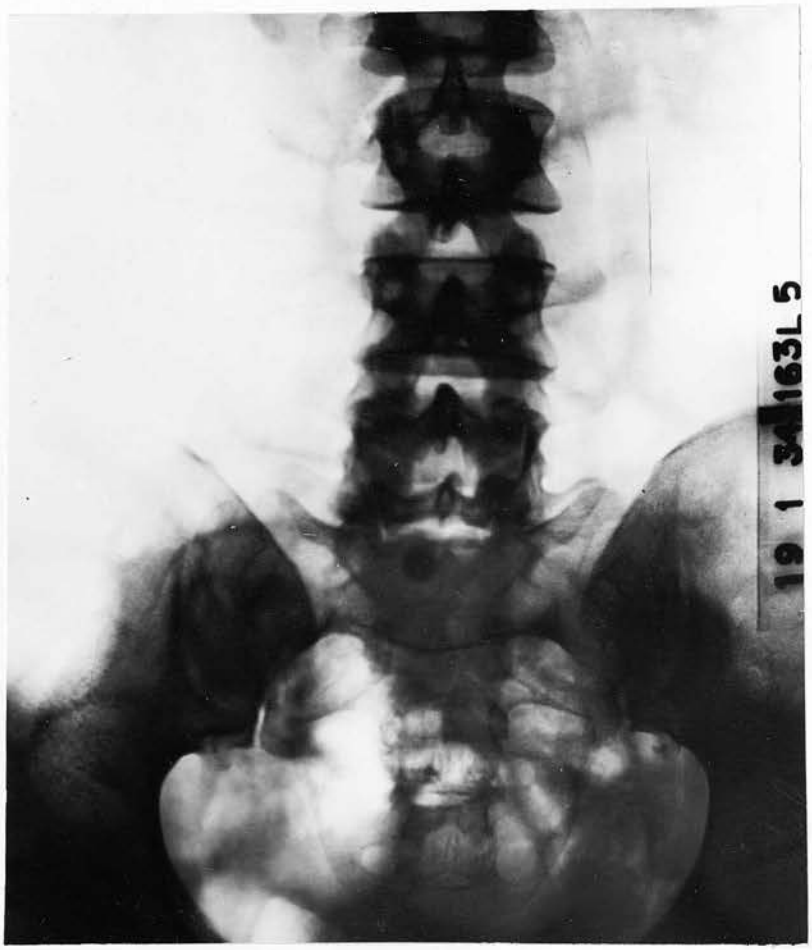


Fig. 3.

The circular shape of the head of the bone peg imtroduced, can be seen in the X-ray.

incised in the middle line, over the bodies of the 5th lumbar vertebra and the 1st sacral vertebra. A bone peg was then introduced into the bodies, passing through the lower part of the 5th lumbar vertebra and into the 1st sacral vertebra. This was hammered firmly into place, and the posterior peritoneum united over it. The packs were removed from the abdomen, which was then closed in layers.

"Arthrodesis of the lumbo-sacral joint."

Progress.-

For three weeks from the time of the operation the patient was kept in a posterior plaster shell, after which she was taken out of the shell and encouraged to move about in bed. Her stitches were removed on the tenth day after the operation, the wound having healed satisfactorily.

When discharged (31.1.34) the patient still had some low back pain, but it was considerably improved by the operation. She was rather stiff but could bend forwards and rise without much difficulty.

Reported.-

11.4.34: Three months after operation the patient was feeling very much better and the pain was getting less. She was X-rayed and the bone peg was seen to

be through the body of the 5th lumbar vertebra into the sacrum: no further slipping had taken place.

27.8.34: The patient was back at work, all pain had gone, there was no stiffness and she looked and felt in perfect health.

CASE II.

Mr D. H., aged 38, admitted 5.1.33, complaining that for the last three months he has had pain and a feeling of weakness in the back, with inability to bend the back, and difficulty in walking.

History.-

Three months ago he injured his back while at work. He was lifting a hutch into position on the rails when his foot slipped and he fell on his knees. The hutch fell over him and he felt a severe stab of pain in his back and heard a snap. After the accident he remained in the mine, but could not work. Since then he has had pain continuously in the low back and it is worse when he bends forward or tries to lift anything heavy. He feels that his left leg is weak and is inclined to drag when walking.

Any movement of the back aggravates the pain, which is always present.

Previous illnesses.-

None.

Physical Examination.-

The patient is a well built, well developed and

healthy looking man. He walks somewhat stiffly and there is apparent dragging of his left leg, but no limp.

Local Examination.-

Inspection: Standing in the erect position, the patient has a straight spine with no deviation to either side. There is a slight projection of the 5th lumbar spinous process with a corresponding concavity directly above it but otherwise no apparent deformity of the vertebral column.

There is no horizontal creasing round the trunk and the abdomen is not prominent or pendulous.

Palpation: There is definite tenderness over the spinous process and left transverse process of the 5th lumbar vertebra. The spine of the 5th lumbar vertebra can be felt projecting posteriorly and above this there is a hollow which is continued up to the 1st lumbar vertebra, where it is flattened out. The 1st lumbar vertebra tends to project slightly, forming a compensatory kyphosis.

Movements: All movements are limited. Flexion to 60° increases the prominence of the 5th lumbar spinous process. Lateral flexion and rotation to both sides are only present to a slight degree. The sacro-spinalis muscles are in definite spasm. There

Fig. 4.

The bow-like outline of the last L.v. can be seen here, with some upward tilting of the spinous process of that vertebra.

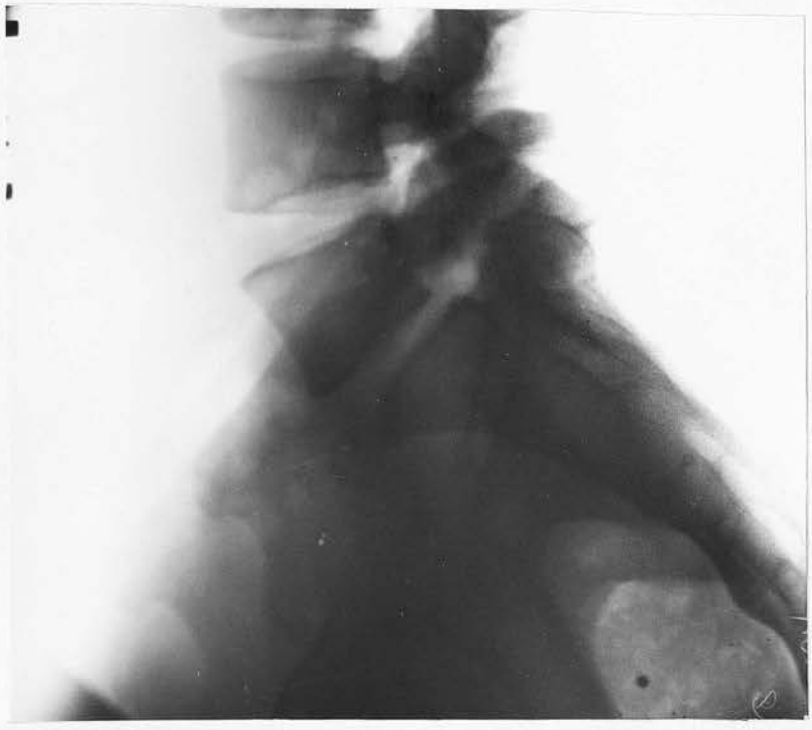


Fig. 5.

Slight elongation of the neural arch and rarefaction of the bone at this point can be seen in the 5th. L.v.

is weakness of all the muscle groups of the left leg in comparison with the right.

X-ray Examination.-

Antero-posterior view: The characteristic bow-like outline can be seen, formed by the 5th lumbar vertebra superimposed on the 1st sacral vertebra. There is a decrease in density of the shadow made by the neural arches of the 5th lumbar vertebra and an increase in length at this point.

There is an upward tilting of the spinous process of the 5th lumbar vertebra which can also be seen in the lateral view.

Lateral view: There is only a slight slipping forward of the 5th lumbar vertebra on the body of the 1st sacral vertebra. The neural arch is elongated and there seems to be some decrease in the density of the shadow there, indicating a possible rarefaction of the bone.

There is a marked increase in the depth of shadow at the upper anterior border of the 1st sacral vertebra, showing that buttressing was present. There is slight increase in thickness of the inter-vertebral disc between the 4th and 5th lumbar vertebrae.

All other systems.- Nothing abnormal can be detected.

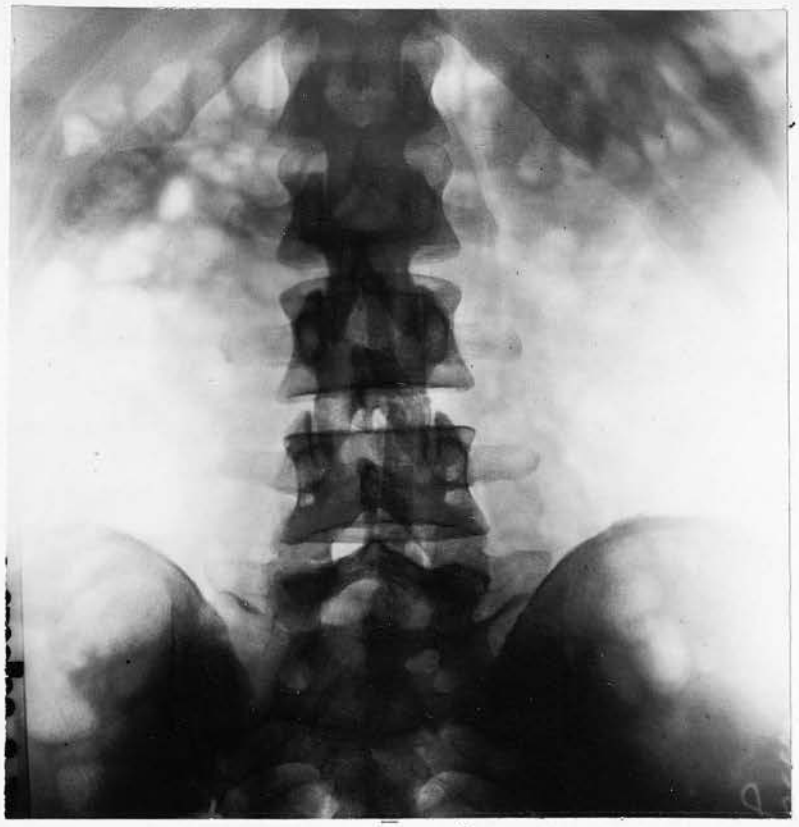


Fig. 6.

The single bone graft from the 2nd.L. to the 2nd.S.v. with the break between the 2nd. and 3rd. L.v. can be seen here.

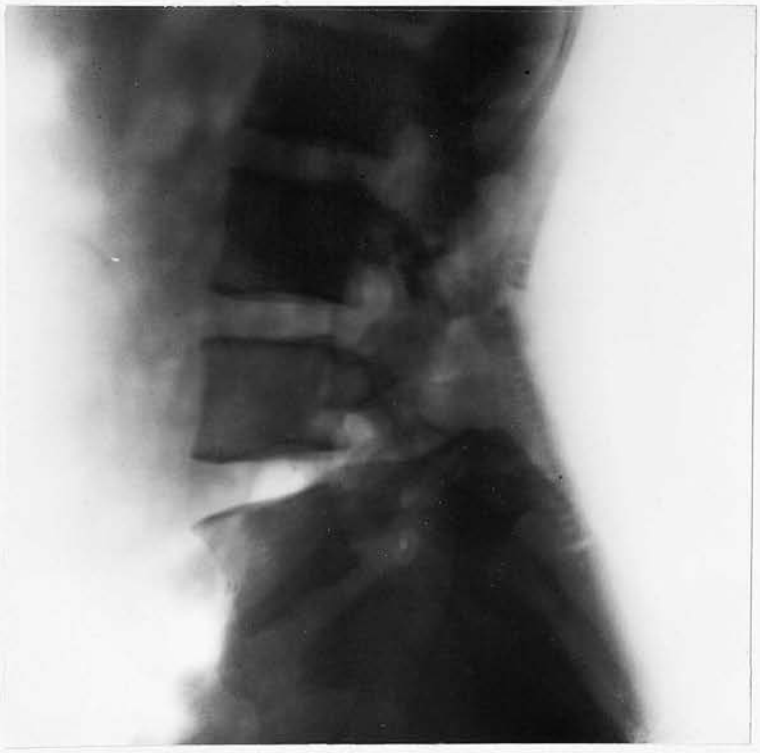


Fig. 7.

The lateral view shows the break in the graft more clearly.

Operation, 13.1.33.

Anaesthetic: Rectal paraldehyde; 1 oz. ether.

In the prone position, an incision was made at the level of the 3rd lumbar-spinous process, passing in a semicircular fashion to the left of the mid line, ending over the 3rd sacral spine. The skin edges were dissected and retracted. The lumbar fascia was then incised in the line of the skin incision and reflected to the right side.

An incision was then made in the mid line, through the supra-spinous ligaments, which were then cleared from the spinous processes by a periosteum elevator. With a sharp osteotome the spinous processes were divided in the middle line and the two halves separated. A gauze pack was inserted to control bleeding and the wound covered with a warm towel.

An incision was next made on the medial side of the right leg, extending from the upper end of the tibia to the lower end. The skin edges were dissected back and, with an electric saw, a wedge of bone 6" x 1/2" was removed from the medial surface of the tibia. The leg wound was then closed.

The graft was prepared by making numerous small cuts with the saw, at intervals of 1/4", extending through the deeper surface of the graft but stopping

short of the periosteal surface, so allowing the graft to be bent.

With the periosteal surface superficially, the graft was then introduced into the gaps in the spinous processes extending from the 3rd lumbar vertebra to the 2nd sacral vertebra.

It was secured in position by bringing the muscles on either side together with interrupted catgut sutures and the lumbar fascia was then united with a continuous catgut suture. The skin wound was closed and a dressing applied and held in position with pressoplast.

"Albee's operation for Spondylolisthesis."

Progress.-

The patient was placed in a posterior plaster shell directly after operation, and made an uninterrupted recovery.

When discharged (30.1.33) both back and leg wounds were satisfactorily healed and the patient was quite comfortable in a posterior shell.

Two months later (22.3.33), while being lifted out of his shell for nursing purposes, he sneezed and felt something give in his back. On X-ray examination it was found that the graft had broken at the

level of the intervertebral disc between the 3rd and 4th lumbar vertebrae.

Readmitted 20.7.33. The patient's general health is good. X-ray examination shows that he can now do without his shell, so he was measured for a poroplastic jacket. Discharged 31.7.33.

Reported.-

8.11.33: Complains of occasional pain in the back for the last few weeks: the jacket is comfortable. X-ray examination shows the broken graft but no further slipping has taken place.

8.8.34: There is some tenderness at the site of the graft.

Readmitted 27.8.34. A posterior shell was made in preparation for a further operation.

Operation, 30.8.34: spinal anaesthesia.

The patient was operated on lying in the posterior shell. The operation was on the same principles as those used in Case I, but a wedge of bone cut from the crest of the right ilium was used instead of a bone peg.

An incision was made in the abdominal wall in the middle line with its centre at the level of the umbilicus. The bowel was retracted and the

posterior peritoneum exposed and incised. The extra peritoneal fat was incised and displaced together with the middle sacral artery. The intervertebral disc between the 5th lumbar vertebra and the 1st sacral vertebra was exposed and part of the disc removed with a gouge. The bone on the distal part of the body of the 5th lumbar vertebra and the proximal part of the 1st sacral vertebra was then bared so that a cavity 1" x 3/4" x 2" deep was made. The hole was packed with gauze soaked in warm saline and the wound covered with a warm towel.

An incision was then made over the right iliac crest and the periosteum divided. A piece of bone immediately posterior to the anterior superior spine, and slightly larger than the cavity mentioned above, was excised. The edges of this block of bone were trimmed and it was inserted into the hole between the two vertebrae. It was firmly wedged into position, then a nail was driven through, fixing it to the sacrum. The posterior peritoneum was stitched over it and the abdomen was closed in the usual way.

The patient was taken back to bed still in the posterior shell. He was making a very good recovery when suddenly, on the third day after operation, he was seized with acute abdominal pain and died shortly afterwards from mesenteric thrombosis (P.M.).

CASE III.

Mr A. F., aged 35, admitted 10.5.34 complaining of pain in the back for eight months.

History.-

Eight months ago the patient was kneeling while at work in the pit when a heavy stone fell on his back and made him fall forwards. He was carried home to bed where he remained for three weeks. After that he began to get about again but experienced severe pain in the low back region, particularly on the right side. He now has great difficulty in leaning over to the left side and in straightening his back from the bending position.

Previous illnesses.-

Measles and whooping cough in childhood.

Physical Examination.-

The patient is a small, slightly built but healthy looking man. He is extremely cheerful and not the type of individual who worries about his health without very good cause.

Local Examination.-

Inspection: He does not stand up well but is

inclined to bend forward a little from the waist. His shoulders are rounded and his muscles rather poorly developed.

There is no deviation of the spinal column, and no horizontal crease round the abdomen. There is a slight projection at the level of the fourth lumbar vertebra with the corresponding hollow just above it, and obvious lordosis.

Palpation: Tenderness was elicited over the spinous process of the 4th lumbar vertebra but nowhere else. Pressure over the lower abdomen in the middle line causes very deep-seated pain.

Movements: Flexion is very poor and causes obvious pain. The projecting spinous process is more easily visible with the spine flexed: hyperextension normal: lateral flexion to the left side very reduced and slightly reduced to the right side.

X-ray Examination.-

Antero-posterior view: In this photograph the bow-like outline, characteristic of the complaint, does not show up clearly as the case is one of a slipping of the 4th lumbar vertebra on the 5th and not the 5th on the sacrum. The lateral part of the line can be seen, but the curve of the bow is hidden by the

Fig. 8.

The bow-like outline here is slightly distorted, as it is the 4th L.v. which has slipped off the 5th.

Fig. 9.

The 5th. L.v. can be seen in its normal position but the 4th. has moved forward on the 5th.

shadow of the sacrum here. There is a definite increase in the density of the shadow where the two last lumbar vertebrae come into closer proximity posteriorly, and the lower edge of the 4th lumbar body is not clearly outlined. This X-ray was taken ten months after his operation, but there is no sign of the iliac wedge which was hammered into place. This may possibly have been absorbed, leaving the roughened surface of the body of the 4th lumbar vertebra which shows in the X-ray.

Lateral view: In this radiogram the condition is obvious. The anterior border of the 4th lumbar vertebra is displaced forward and breaks the continuity of the curve normally found when a line connects the anterior surfaces of the bodies of all the lumbar and sacral vertebrae.

Ullman's sign is present, and the increased lordosis so marked in this case, shows.

There is an increase in the width of the intervertebral space anteriorly, and a decrease posteriorly, while the neural arches are slightly elongated and increased in density. The 5th lumbar vertebra is seen to be in its normal position as regards the sacrum, but the other lumbar vertebrae have been carried forward along with the displaced 4th. Here the

operative interference with the distal surface of the body shows up clearly in a rather blurred outline of the 4th lumbar vertebra.

All other Systems.- Nothing abnormal to note.

Operation, 12.5.34.

Anaesthetic: Spinocaine.

The operation has already been described, as the second of the two performed on the last case (Case II), but the wedge of ilium was merely hammered firmly into place between the 4th and 5th lumbar vertebrae and no screw was used to keep it there. The posterior peritoneum was closed over it and the abdominal wound united in layers.

Progress.-

The patient was placed in a posterior shell directly after the operation. When discharged (23.5.34)the abdominal and iliac wounds were satisfactorily healed and the plaster shell fitted comfortably.

Reported.-

14.7.34: The posterior shell was removed and he was fitted with a poroplastic jacket.

27.8.34: There is still very slight pain in the back but the stiffness is better and the patient seems

well. He finds the poroplastic jacket comfortable to wear and feels safer in it than without any support.

CASE IV.

Mrs L., aged 34, admitted to the Simpson Maternity Hospital 12.2.34, for an examination under an anaesthetic with a view to induction of labour.

History.-

Till she was 14 years of age, the patient was a healthy girl. She worked in the house and was accustomed to carrying her young brothers and sisters about. In her fourteenth year she started having pain in her back over the 5th lumbar vertebra and the 1st sacral vertebra. The pain did not radiate down her thighs but it was made worse by standing for any length of time, or on walking. Rest, either lying down or sitting, relieved it. In character it was more of a dull ache than an acute pain.

She does not know of any fall or accident which might have caused the pain, and she did not consult any one at the time as her mother thought it was probably due to the approaching menarche.

The pain was present for about two years, then gradually passed off. Since then she has had no recurrence and has been perfectly healthy.

The patient was married in 1927 and has had five healthy children. The first was a spontaneous

Figs. 10 - 11.

Photographs of the patient showing the approximation of the ribs to the iliac crest, thependulous abdomen, and the general shortening in stature of the patient.

Fig. 12.

Footprints of the patient illustrating the typical tight-rope walker's gait.

delivery, the next three were instrumental deliveries and the last child was spontaneous, weighing $7^{1}/2$ lbs. The other children weighed between 8 and 9 lbs. each at birth.

Previous Illnesses.-

Scarlet fever and rheumatism when a child.

Physical Examination.-

The patient is a small woman, 5 ft. high, tending to stoutness. She looks and feels well, has a clean tongue and a good appetite. She walks placing one foot directly in front of the other in the typical "tight-rope walker's gait".

Local Examination.-

Inspection: Mrs L. shows all the outward signs of an advanced spondylolisthesis. She has a pendulous abdomen, marked horizontal creases round the waist and a vertical furrow over the lumbar spine. There is obvious "telescoping" of the vertebral column, with the result that the ribs are resting on the iliac crests. There is no lateral deviation of the spine and no marked lordosis.

Palpation: There is slight tenderness over the right lumbo-sacral joint, but none over the body of

the vertebrae. The spine of the 5th lumbar vertebra can be felt projecting posteriorly but cannot well be seen, owing to the adiposity of the patient. The spine of the 1st lumbar vertebra can be felt forming the top of a compensatory curve, concave inwards, with a furrow running down from this spine to the spine of the 5th lumbar vertebra.

A finger cannot be introduced between the lower border of the ribs and the iliac crests on either side, but the thin edge of a ruler just fits into the space.

Movements: Movement in all directions is slightly limited. Flexion is limited beyond 90°; extension is slight, while lateral bending is poor. There is no pain on movement except on deep palpation over the lumbo-sacral articulation. There is no muscular spasm.

Vaginal Examination under chloroform.-

The pubic angle is slightly narrowed. The sacral curve seems more vertical than is usual and when the examining finger is passed up the anterior wall of the sacrum it passes into a bony rectangle. This is formed by the sacrum and the 5th lumbar vertebra overhanging it.

Two measurements of the true conjugate were obtained -

Fig. 13.

The bow-like outline is very clearly shown though the pr-sence of the foetus and amniotic fluid somewhat obstructs the view.

Fig 14.

A marked degree of spondylolisthesis is present, The 5th. L.v. having slipped over the edge of the sacrum into the pelvis.

(1) From the pubis to the lower edge of the overhanging vertebra, $4\frac{1}{2}$ inches, and

(2) From the pubis to the top of the 5th lumbar vertebra, which was $4\frac{3}{4}$ inches.

Nothing else abnormal was detected per vaginam.

X-ray Examination.-

Antero-posterior view: The foetus can be seen lying in the transverse position. The bow-like outline of the body and transverse processes of the 5th lumbar vertebra is very distinct and indicates a marked forward slipping of the body of the last lumbar vertebra.

No decrease in density of the neural arches can be made out but there is a widening of the intervertebral space. The spine of the 5th lumbar vertebra is tilted upwards.

Lateral view: Here, extensive slipping of the body of the 5th lumbar vertebra can be seen, so that its distal border is partly in contact with the anterior border of the sacrum. The neural arch is slightly elongated and less dense than that of the 4th lumbar vertebra. There is an increase in the density of the shadow at the junction of the slipping body with the sacrum, indicating a possible increase in the bony structure in the form of buttressing. The marked lordosis can be well seen, though on the surface

this is not so clear owing to the stoutness of the patient. The "superficialization" of the sacrum can also be seen.

All other systems.-

Nothing abnormal could be detected.

Treatment.-

As the patient had no complaint to make about her back, it was causing her no inconvenience in any way, and in view of the fact that she had had five children, two of which were spontaneous deliveries, no treatment was recommended and operative interference was considered unnecessary.

CASE V.

Mr C. F., aged 37, admitted 9.2.34 complaining of pain between the shoulders for 17 months, also occasional severe pain in the epigastrium.

History.-

Eighteen months ago the patient received a severe mental shock, soon after which he experienced pain between his shoulders. This was dull in character and always present except when he was seized with severe pain in the epigastrium. The later was acute, and relieved by the eructation of gas. It was worse when he went to bed or lay down, at which time the shoulder pain was relieved.

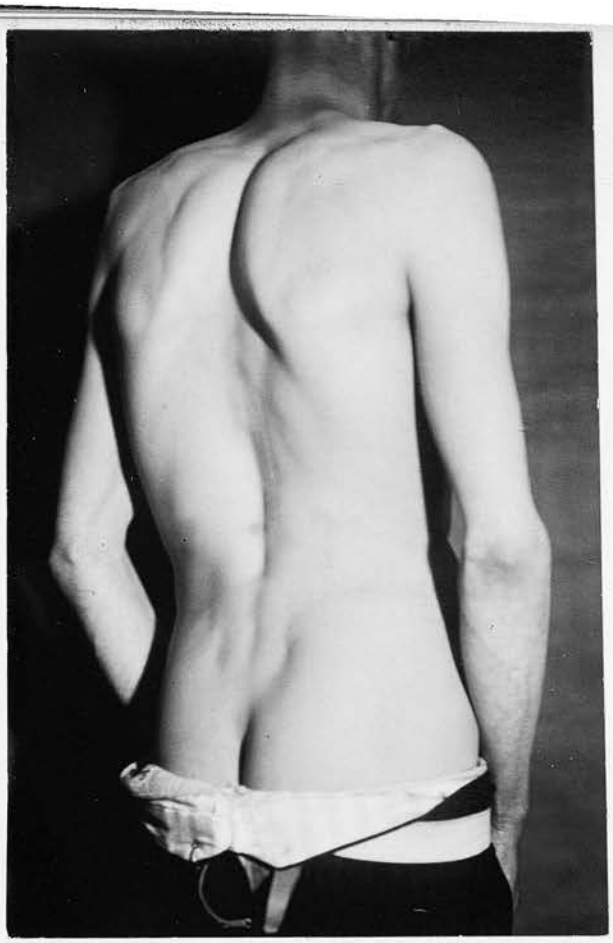
There is no relation between food and pain, his appetite is good and his bowels are regular.

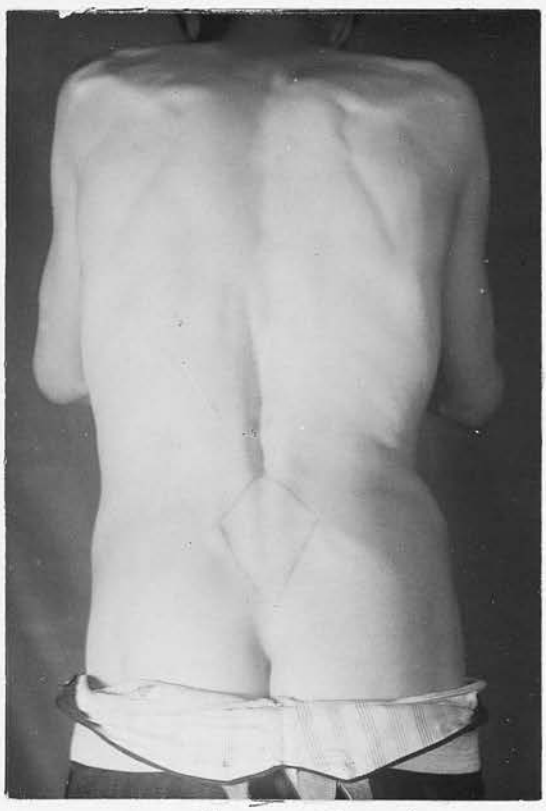
Previous illnesses.-

Shingles severely eight years ago.

Physical Examination.-

Patient is a large man, pale and rather unhealthy to look at. He appears to be very introspective. He gives a very indefinite history in a wandering, unsatisfactory manner.





Figs. 15 -16.

Photographs showing the depression over the lumbar vertebrae and the flattening of Michaele's rhomboid.

Local Examination.-

Tongue furred: teeth good.

Abdomen moves freely on respiration. There are two white patches on the epigastrium which the patient says came when he had shingles.

There is no tenderness or pain at the time of examination; no abmormal masses can be felt. There is no rigidity and no enlargement of the liver or spleen.

Genito-urinary system: Nothing abnormal could be detected.

On examination of the patient's shoulders nothing could be found to cause the pain. The spine was perfectly normal and moved easily without pain.

On examination of the lumbar spine, however, a well marked furrow was seen, running from the prominent 1st lumbar vertebra spine to the 5th lumbar vertebra. Michaele's rhomboid was flattened from above downwards, and the typical creases running round the trunk between the ribs and the iliac crests were seen, though not very marked. The spinous process of the 5th lumbar vertebra can be felt lying about half an inch to the left of the spine of the 1st sacral vertebrae. This irregularity does not show on the surface

Fig. 17.

The break in the neural arch of the 5th. L.v. and the bow-like outline, together with a slight deviation of the spine can be seen.

Fig. 18.

The width of the intervertebral space can be seen to be enlarged, although the degree of spondylolisthesis is slight.

though a slight deviation of the spine can be seen, most marked in the thoracic region.

Palpation: The prominent 5th lumbar spine can be felt, but there is no tenderness on pressure over any part of the vertebral column.

Movements in all directions are good and quite unrestricted.

X-ray Examination.-

Antero-posterior view: Deviation of the spinal column is seen, also the characteristic bow outline. There is a definite, though slight, break in the continuity of the neural arch of the 5th lumbar vertebra, with a tilting upwards of the spinous process of that vertebra. The intervertebral space is increased.

Lateral view: A slight degree of spondylolisthesis is present. The 5th lumbar vertebra can be seen to have slipped forward on the sacrum a short way, with a lengthening of the neural arch. The widening of the intervertebral space is well marked. There is no evidence of buttressing on the sacrum, as the condition is only slight.

The furrow seen on the surface can be clearly made out by the position of the other lumbar vertebrae.

All other systems were examined with extra care owing to the history of pain in the epigastrium and shoulders, but nothing whatever could be found abnormal.

Treatment.-

10.2.34: The patient was fitted with a supporting jacket. As the pain was only in the shoulders, no operation for spondylolisthesis could reasonably be performed.

Progress.-

12.2.34: Discharged with support fitting comfortably.

23:5.34: X-rayed; has had pain in the right costal margin going round to the back, but absent now.

8.8.34: Reported; pain felt over 5th lumbar vertebra going down the back of the right leg; slight stiffness of the lower lumbar spine.

X-ray shows further slight slipping of the 5th lumbar vertebra, with a definite break in the neural arch: name put on waiting list.

CASE VI.

Mr J. K., aged 22, admitted 1.1.34 complaining of pain in the left hip and down the back of both legs for one month.

History.-

Six months before admission the patient developed an aching pain in the left calf which was worse at night, and aggravated by walking or going upstairs. It was not always present; sometimes for as long as a week he would be entirely free from any pain.

One month before admission his right hip and leg "felt sore" on rising in the morning or after resting for any length of time. Two weeks later the pain got much worse and at the same time his left hip and leg began to trouble him. The left sided pain was aggravated by lifting weights or walking and was the cause of the patient having to stop work.

Previous illnesses.- None.

Examination.-

General: The patient is a thin, delicate-looking youth, 5' $4\frac{1}{2}$" high and only weighing $7\frac{1}{2}$ stone. Mentally slow, he forms rather an unreliable witness.

He has a long, thin chest, of the asthenic type, and his ribs are only separated from the iliac crests on both sides by the width of one finger.

His appetite is good, there is no constipation, he has no urinary symptoms and his general health is good.

Local Examination.-

Inspection: There is no alteration in his gait, and no muscular wasting. The left iliac crest is slightly more prominent than the right one when the patient is standing. There is no spinal deviation, but the spinous process of the 5th lumbar vertebra is very prominent and can be seen projecting beyond the other spines.

Palpation: There is no tenderness elicited anywhere over the sacro-iliac joints, or lumbar spine, or lumbo-sacral joints. The projecting 5th lumbar spinous process can be easily felt, and there is a distinct groove over the spinous processes of the other lumbar vertebra with a positive Tcherkin's sign. Michaele's rhomboid is flattened from above downwards.

Movements: All movements of the lower spine are limited. Slight flexion increases the projection of the 5th lumbar vertebra.

Fig. 19.

An extensive degree of slipping of the 5th. L.v. off the sacrum can be seen.

Latent flexion and rotation are extremely limited either passively or actively, but there is definite tonus of the muscles.

X-ray Examination.-

The antero-posterior radiogram was extremely poor and no satisfactory reading could be made.

Lateral view: Extensive slipping of the body of the 5th lumbar vertebra can be seen, with the distal border of the body in direct contact with the anterior surface of the sacrum. There is no obvious buttress formation.

This X-ray is also very poor, but the neural arch appears to be slightly elongated and rarefied. The 4th-5th lumbar intervertebral space is widened compared with that of the 4th-3rd.

All other systems.- Nothing abnormal could be detected.

Treatment.-

Since such a gross degree of slipping of the 5th lumbar vertebra had taken place it was decided that no operation could be of any assistance to the patient, so he was fitted for a supporting jacket. This he found eased the pain and he was able to start work again.

The patient lives in Beattock and since his discharge about one year ago he has not reported at the Infirmary.

INTRODUCTION.

Spondylolisthesis, or the gradual gliding of a vertebra (σπονδυλος), was described in 1853 by Kilian[1]. It is defined as "a displacement forwards of the whole spinal column, either in relation to the 5th lumbar vertebra and sacrum and pelvis, or the sacrum and pelvis" (Albee[2]).

The condition was primarily of interest to the obstetricians rather than the surgeons owing to the reduction of the pelvic diameter and the consequent difficulty in labour which the condition produces. Because of this, spondylolisthesis was believed to be more common in women than men, but recent observers have found it to be about equal in both sexes. In fact, Sir Arbuthnot Lane[3] goes so far as to say that it is the normal condition in coal-heavers.

Towards the end of the last century (1880-90) Neugebauer[4] of Warsaw produced a complete bibliography from the obstetrical point of view, and was the first observer to make a complete and thorough study of the condition.

In the following thirty years many other writers have referred to the condition, and to-day it is recognised as one of the causes of low back pain,

although in innumerable cases the condition is well advanced without any complaint whatever from the patient.

Since the advent of X-rays, spondylolisthesis has been brought more to the notice of surgeons, particularly orthopaedic surgeons, owing to the typical features of the condition portrayed in radiography.

Several observers base their diagnosis on the antero-posterior view, but these are apt to be misleading in view of the possible rheumatoid changes in the joint. Lateral X-ray photographs are, however, quite conclusive.

In 1927, Brailsford[5] in his X-ray examination of 3000 spines found five cases of spondylolisthesis. Since that date he has seen seven other cases. In the Mayo Clinic, from 1918-1931, 148 cases out of 207 examined were males.

In the last nine months one has seen eight positive cases and at least three patients with low back pain showing what might be explained as a pre-spondylolisthesis, in the X-ray photographs. The youngest case here is 11 years old but Meyerding[6] has recorded the case of a girl aged 5 years.

EMBRYOLOGY.

Mesodermic in origin, the vertebral column starts as a primitive skeletal axis. When the embryo is 2.5 mm. long, at the end of the 3rd week, the neural groove closes, except for the caudal and cranial regions.

The "membranous column", formed by a continuous sheath of mesodermal tissue enveloping the neural tube and notochord, chondrifies to form the "cartilaginous column". This change occurs at the beginning of the 2nd foetal month.

Two symmetrical nodules of cartilage appear on each side of the notochord and eventually surround and constrict it - to form the first (cervical) vertebra. When these two pieces fuse, the body of the vertebra is formed.

Between the chondrifying vertebral bodies, scleratogenous tissue forms the intervertebral fibrocartilaginous discs. Here the notochord is only slightly compressed, so appears on cross-section as a swelling.

The lateral portions near the notochord now extend -

(a) Dorsally round the vertebral canal and are known as the vertebral bow; and

(b)/

(b) Ventrally, round and beneath the notochord, and are known as the hypochordal bow. Later this disappears.

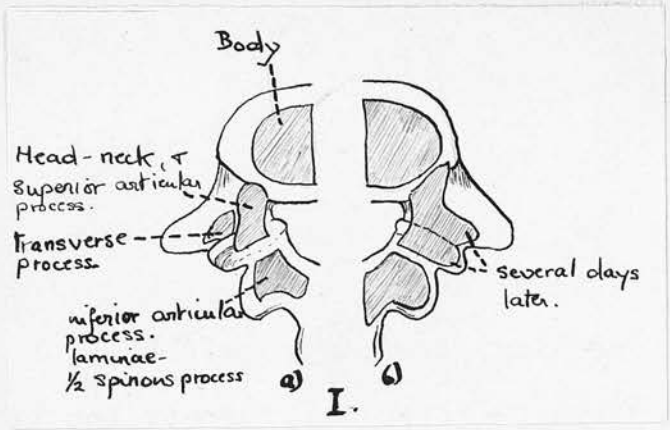
The vertebral bow chondrifies and forms the cartilaginous vertebral arch, the extremities of which unite at the 4th intrauterine month. (Defective development here results in a spina bifida.)

From these cartilaginous vertebral arches rise the spinous and transverse processes, and eventually the arches fuse with the body of the vertebra.

Some writers believe the arches and spinous processes develop as an elongation and extension from the main body and not independently.

There are three primary centres of ossification for each vertebra. The one for the body appears at the 15th week. This is first dorsal to the notochord. but eventually surrounds and displaces it. Occasionally two centres form and later unite. By the end of the 5th month primary ossification centres are present in all the vertebrae.

At the 7th week of intra-uterine life a centre appears for each lamina at the roots of the articular processes. This first shows near the base of the superior-articular processes, then it extends back to the lamina, laterally to the transverse process and forwards to the root of the vertebral arch.



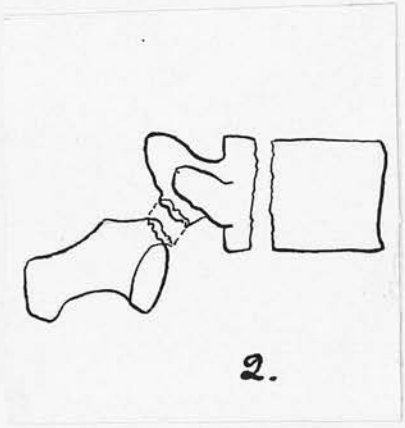


Fig. 20.

(1) Ossification of 5th. Lumbar vertebra.
(2) Lateral or above in section.

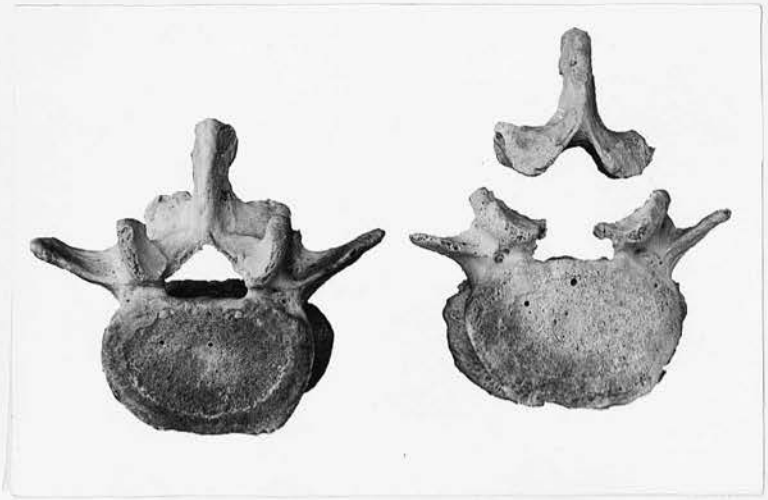


Fig. 21.

Photograph from an anatomical specimen showing complete separation of the 5th. L.v. into two parts.

The vertebral arches are separated from the main body by a cartilaginous strip till the 5th - 6th year. The laminae start to fuse to the body in the median plane at birth in the lumbar vertebrae, but are not closed in the sacrum till the 7th - 10th year.

Secondary centres - five in number - appear at puberty and fuse at 25-28 - one for the spinous process, one at the tip of each transverse process, and one for each mamillary process. Two epiphyseal plates appear on the body - one superiorly, one inferiorly - and fuse in the centre at 25 years.

According to Rambaud and Renault[7], the vertebral arch of the 5th lumbar vertebra sometimes develops from two primary centres when the arch is divided by a synchondrodial joint running obliquely between the superior and inferior articular processes. There is then a congenital defect which probably persists throughout life, dividing the vertebra into two distinct parts. The posterior part consists of the spinous process and inferior articular facets; the anterior part consists of the body, transverse processes, superior articular facets and mamillary processes. The two parts are united throughout life by the strip of cartilage above mentioned. This

ANATOMY.

Vertebral bodies are composed of spongy bone, with the superior and inferior surfaces slightly concave dorso-ventrally, and from side to side, due to a slight thickening of the bone at the margins. These surfaces give attachment to the intervertebral fibrocartilage between the bodies of the movable vertebrae.

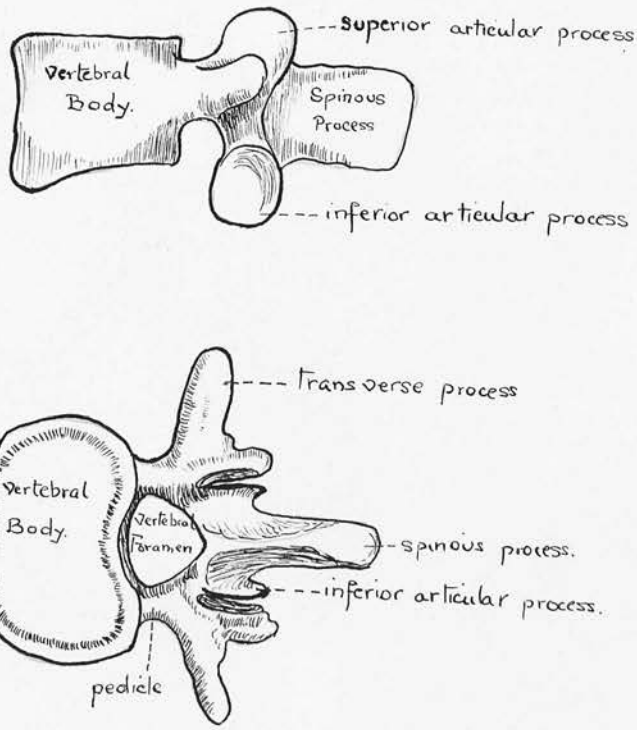
The vertebral arch, connected with the body posteriorly, is formed by the pedicles and laminae, and encloses the vertebral foramen. The arch supports the spinous processes.

Each pedicle is compressed from side to side and has rounded upper and lower borders. Posteriorly the pedicles unite with the laminae to form the spinous processes.

The superior articular processes are formed at the junction of the pedicles and laminae, and incline backwards. The inferior articular processes, inclining forwards, are in a corresponding position on the lower part of the arch.

Lumbar Vertebrae.

These are the largest movable vertebrae in the body. The vertebral body is kidney-shaped with the



Lumbar Vertebra.

transverse diameter about half that of the antero-posterior. The pedicles are directed horizontally backward and are shorter and stouter than those of other vertebrae. The laminae are broad and lie nearly vertically.

The spatula-shaped spinous processes have a thickened posterior margin and are directed backwards and downwards.

The transverse processes are nearly horizontal and have a slight upward and backward tilt.

Fifth Lumbar Vertebra.

This is the largest vertebra of all. The interior surface of the body is cut away at the expense of the posterior part and is consequently thicker anteriorly than posteriorly.

The transverse processes are stouter and more pyramidal in shape than those of the other vertebrae. They rise from a broad base at the side of the body, as well as from the pedicle, and are directed laterally, backwards and upwards.

Professor Brash states that there is a gradual increase in the size of the transverse processes of the lumbar vertebrae from the 1st to the 3rd but that the 4th is shorter, and the 5th longer than the 4th.

Correspondingly, the intervertebral disc of the lumbo-sacral joint is wider anteriorly than posteriorly, making allowance for the lumbo-sacral angle.

This joint is set vertically beneath the occipital condyles and it marks the commencement of the sacral curve backwards.

This curve and the thoracic form the primary curves in the foetus. When the head is extended and elevated, the forward cervical curve appears, and when the child starts to stand and gain the erect posture the forward lumbar curve appears.

As the child grows, the lumbo-sacral angle is increased by the constant pressure, due to the weight of the body, exerted on the joint.

Anteriorly, the weight is borne by the front of the bodies of the vertebrae and the intervertebral discs and posteriorly by the articular processes of the vertebrae.

In health, the normal body curves are maintained by good muscle tone and ligaments and no strain is felt. When the musculature is weakened by disease or ill health, the ligaments and articular processes are strained and an over-exaggeration of the normal curve results.

The lumbo-sacral joint and the 5th lumbar vertebra

suffer at this time and also if there is any congenital bony malformation or weakness.

According to Brailsford[5], in his study of the lumbo-sacral spine, this joint is kept in position by numerous factors.-

(1) The intervertebral disc acting as a shock absorber between the body of the 5th lumbar vertebra and that of the 1st sacral segment.

(2) Anterior longitudinal ligament attached to the intervertebral discs and vertebral bodies.

(3) Posterior longitudinal ligament attached to the posterior surfaces of the bodies.

(4) Articular ligaments and capsules.

(5) Interspinous ligaments from the tip of one spinous process to the base of the next.

(6) Supraspinous ligaments from the tip of one spinous process to the tip of the next.

(7) Lateral lumbo-sacral ligament from the transverse process of the 5th lumbar vertebra to the base of the sacrum.

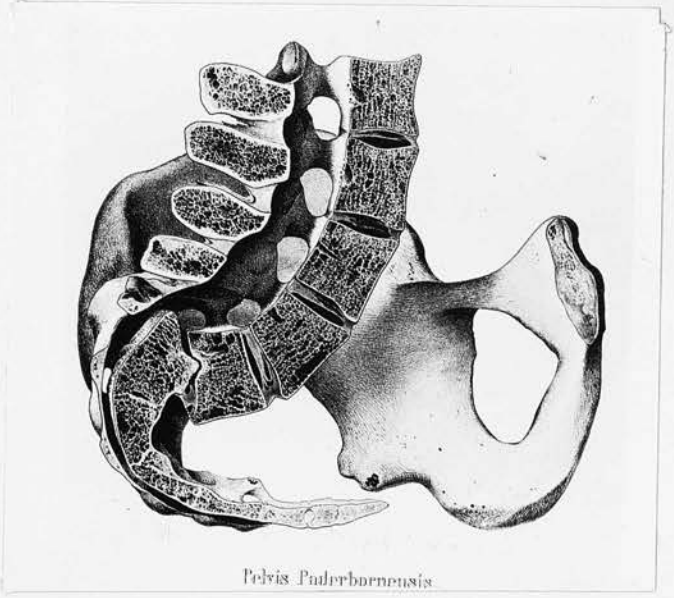
(8) Ilio-lumbar ligament consisting of - (a) transverse part; (b) posterior part; (c) descending part; from the transverse processes of the 5th lumbar vertebra to the iliac crest (posterior-superior).

Lovett[8] points out that the crucial point in spondylolisthesis is more the antero-posterior elongation of the body of the vertebra than the subluxation, and Neugebauer classifies the causes of the separation of the anterior and posterior parts of the spondylolisthetic vertebra in the following way.-

"(1) Separation on one or both sides between the body and the laminae of the vertebra due to - (a) defective development; (b) fracture.

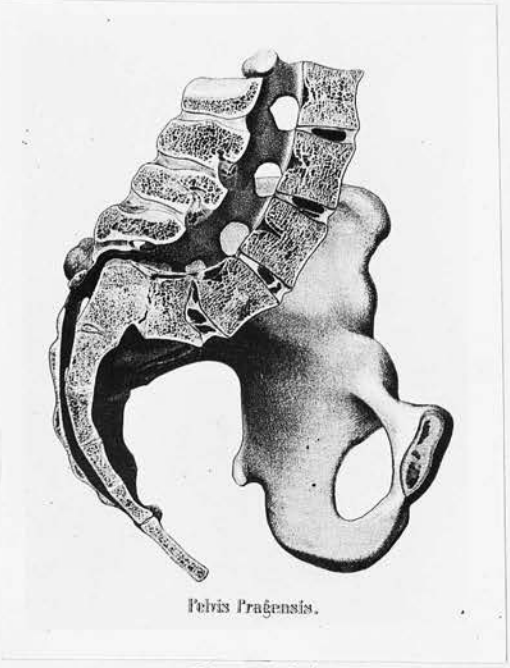
(2) Primary disease of the sacro-vertebral articulation.

(3) Vertebral deformity due to the superimposed weight and bony changes resulting from pressure."



Pelvis Paderbornensis

Fig23.



Pelvis Pragensis.

Fig. 24.

Two specimens of advanced spondylolisthesis shown in section.

ETIOLOGY.

In 1888 Fancourt Barnes wrote - "It is now generally accepted that this deformity (spondylolisthesis) in the majority of cases results from a solution of continuity across the neural arch of the 5th lumbar vertebra between its superior and inferior articular processes".

Before this, Rokitansky and Kilian[1] had said that the condition was due to caries, and other observers believed rickets, osteomalacia, T.B. or hydrorrachis were responsible factors.

Herrgott[9] believes that inflammation of the arch caused a loss of resistance and thus a solution of continuity, but Neugebauer states that it may as easily be congenital as acquired, in which case inflammation is not proven.

Magnuson[10], Willis[11] and Hey Groves[12] are further supporters of the improper development theory.

Lane[3] and Roberts believe that excessive weight bearing produces thinning and elongation of the neural arch.

Kleinberg[13] favours a developmental defect in the lumbo-sacral region, affecting the ligamentous structures and body, and the addition of trauma to

precipitate the condition.

Henry[14] suggests trauma of modern industry, probably shearing off superior processes of the sacrum. All his cases show nerve involvement of some kind, and the progressive lesion leads to stretching of the ligaments, then dislocation.

Albee[2] believes in trauma affecting the body of the vertebra while the laminae and spinous processes remain in situ.

The vertebra may be subluxated in part, or the body and anterior half of the arch may be dislocated while the posterior portion remains in place, and it may eventually be ankylosed to the sacrum.

It is now recognised that there are several etiological factors causing spondylolisthesis and they may be classified under the following headings.-

(1) Congenital

(2) Trauma

(3) Pre-spondylolisthesis

(4) Occupational strain

(5) Pregnancy.

Congenital Abnormalities.

It has already been pointed out that spondylolisthesis occurs when five primary centres of

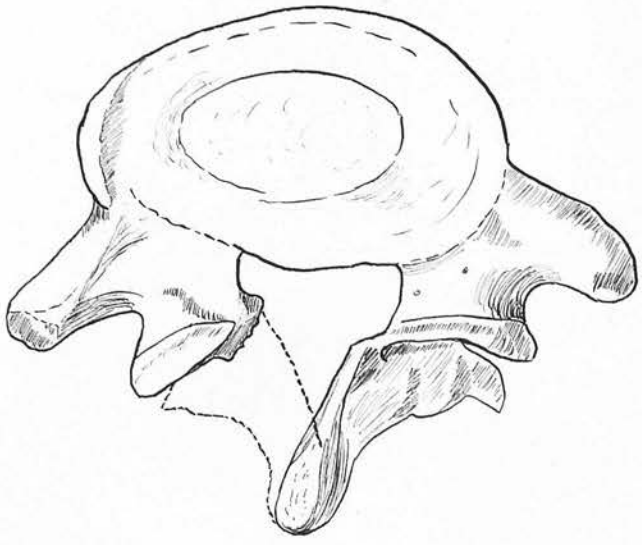
ossification appear in a vertebra instead of the usual three. There are in these cases two centres in each neural arch - one near the body and one near the inferior articular process.

Occasionally fusion between these two centres takes place on one side of the arch only and a unilateral spondylolisthesis results with a compensatory curvature of the whole spinal column due to the slight lateral rotation of the body of the vertebra (Lambl[15]).

When the two primary centres remain unossified, a false joint results and is the cause of spondylolisthesis.

In a patient with this abnormality, a fall on to the buttocks, or an injury to the spine may cause a displacement forward of the spinal column, the posterior part of the 5th lumbar vertebra remaining in position owing to the articulation of the inferior articular facets with the sacrum. The rest of the spine goes forward on the body of the 5th lumbar vertebra, forming an anterior convexity and corresponding posterior concavity which can frequently be seen on examination of the patient's back. The 5th spinous process can be felt (and often seen) projecting backward just below this concavity.

Some cases show a backward slant of the other



Unilateral spondyloschise & spina bifida in a lumbar vertebra. After Lambl.

Fig. 25.

vertebrae of the lumbar spine, in order to keep the normal posture of the body. This can be seen as a projection on the back of the patient at the level of the 1st lumbar vertebra (Tchirkin's sign[16]).

A spina bifida occulta is not infrequently found associated with spondylolisthesis.

Le Double[17], in his "Traite des Variations de la Colonne vertebrale de l'homme" produces a diagram taken from one of his cases, in which part of the posterior part of the vertebra is absent altogether. On one side the centre and neural arch - called by him the semi-arc - are in their normal position, but on the other side the inferior articular process, laminae and part of the spinous process are missing. The pedicle, superior articular and transverse processes on this side are attached to the body of the vertebra. A spina bifida occulta is also present in this case.

As yet it is not known when the vertebra first begins to slip. Robert, in 1885, proved exp rimentally that a complete subluxation of the 5th lumbar vertebra was impossible without serious damage to the lumbo-sacral joint and to the ligaments at this region which maintain the continuity and stability of the vertebral column. After sawing through the

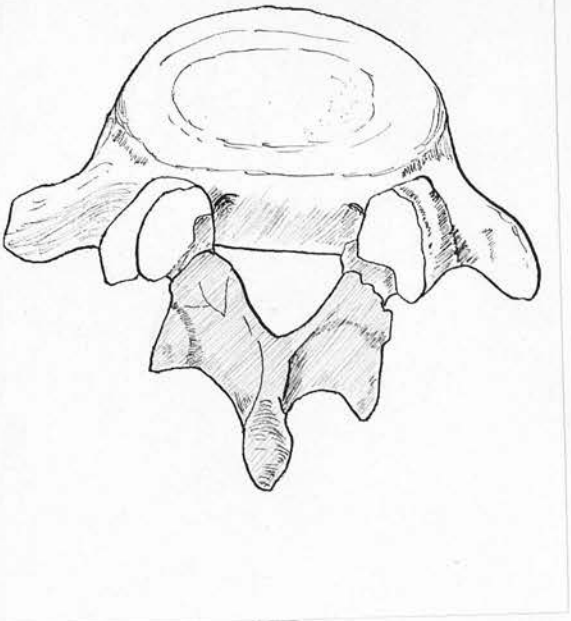


Fig. 26.

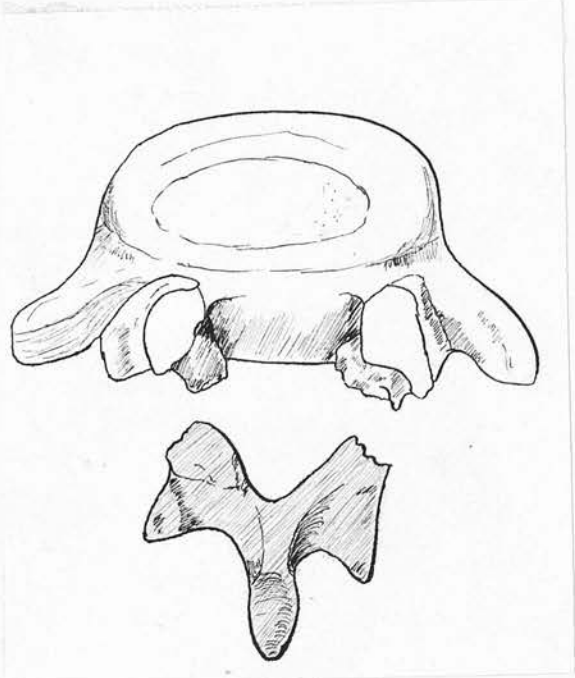


Fig. 27.

Bilateral spondyloschise of 5.L.V. with free posterior part.

After Lambl.

inter-articular portions of the laminae the dislocation was easily produced. No cases in young infants are reported with this condition, possibly because it is partly due to weight bearing that the slipping occurs, and the weight of a child's body would hardly be enough to cause the condition. Also, few children receive severe back injuries - though they may probably fall, landing on their buttocks, but have sufficiently elastic and healthy musculature to withstand the shock without affecting the lumbo-sacral region.

It is not unlikely that spondylolisthesis is caused in childbirth. A mother with the condition has a difficult labour due to the reduced diameters and a difficult childbirth causes spondylolisthesis in the adult, by traction and pulling at birth.

It may take years before the condition is recognisable as a properly developed spondylolisthesis but may remain as a pre-spondylolisthesis or spondylolysis, in which the neural arches are not actually separated but have a congenital weakness in the body structure.

Neugebauer[4] called this condition "spondyloschise", meaning a separation of the lumbar vertebra into two parts - the posterior part consisting of the spine and inferior articular processes and laminae and the

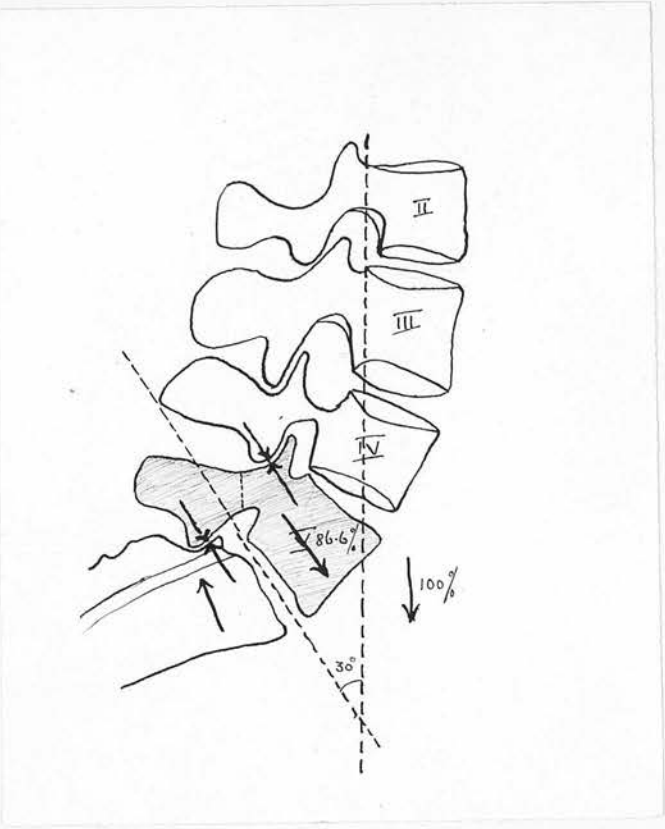


Fig. 28.

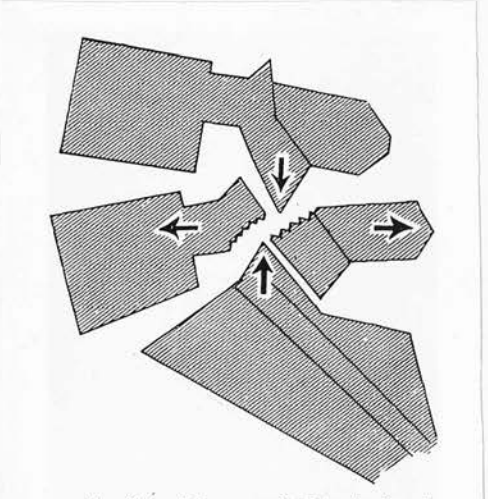


FIG. 282.—Diagrammatic lateral view of lower spine to show the influence of sacral and lumbar wedges upon the last lumbar vertebra.

Fig. 29.

Diagram showing forces acting on "isthmus" of 5. L.V.

After Chandler.

anterior part consisting of the rest of the vertebra. The posterior part is shaped like a V, the point of which faces posteriorly. There is no slipping of the 5th lumbar vertebra forward in this case.

Sandifort has described this state of affairs in the 1st sacral vertebra, Broca in the 1st lumbar vertebra, Treub, Lane[3] and Neugebaur in the 4th lumbar vertebra, while Neugebauer[4] has described it in the 3rd, 4th and 5th lumbar vertebrae in the same spine.

Whitman[18] gave the name of pre-spondylolisthesis to cases in which the lumbo-sacral angle approached 90^{o}, and states that it is not uncommon to find excessive lordosis in people who have had rickets, osteomalacia, etc., without any sign of spondylolisthesis.

In increased lordosis, wedging of the spinous processes of the lumbar vertebrae would tend to prevent any degree of slipping provided the vertebrae remained intact. If spondylolisthesis results, the 5th lumbar vertebra spinous process is pushed upwards, and the wedge like portion of the sacrum and the weight of the column from above crush the 5th lumbar vertebra with the resulting elongation of the neural arch.

The apex of this wedge is formed by the articular facet of the sacrum which is driven upwards and splits

FIG. 286.—Severe spondylolisthesis with rotato-scoliosis.

Fig. 30.

Spondylolisthesis with rotato-scoliosis.

the 5th lumbar vertebra into two portions, at the site of congenital non-union. Weight, in the lumbar curve, tends to be displaced from the bodies to the laminae, hence the 5th lumbar vertebral lamina will be nipped between the posterior part of the sacrum and the inferior articular process of the 4th lumbar vertebra.

If this is unilateral - rotato-scoliosis results, with increased movement of the lumbar spine. This is undoubtedly not a cause of spondylolisthesis, but may be an accessory factor.

Le Double[17] states that spondylolisthesis is not found in any particular race or sex, but about equally in men and women. It is more constant in the 5th lumbar vertebra than any other vertebra in the column. According to Lange[19] it is present in 10-12% of all skeletons and Jendrzichinsky reports it in 5%. Le Double[17] has found it in only 11 out of 200 spines and all in the 5th lumbar vertebra.

In spondylolisthesis the semi-arcs or neural arches have lengthened with a resulting enlargement of the vertebral foramen. This is because there is a lack of bony continuity in this region, and the weight of the body tends to make the body of the 5th lumbar vertebra slip forward on the oblique plane of the sacrum.

Fig. 31.

Anatomical specimen showing the division of the vertebra into two parts.

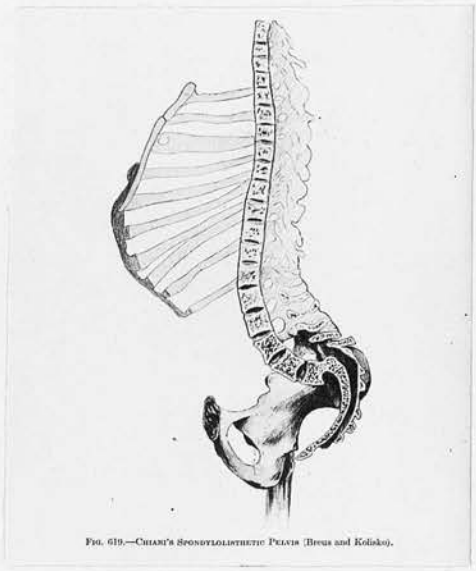


Fig. 619.—Chiari's Spondylolisthetic Pelvis (Breus and Kolisko).

Fig. 32.

Spondylolisthetic pelvis showing the relation of the vertebral column to the pelvis in such a case.

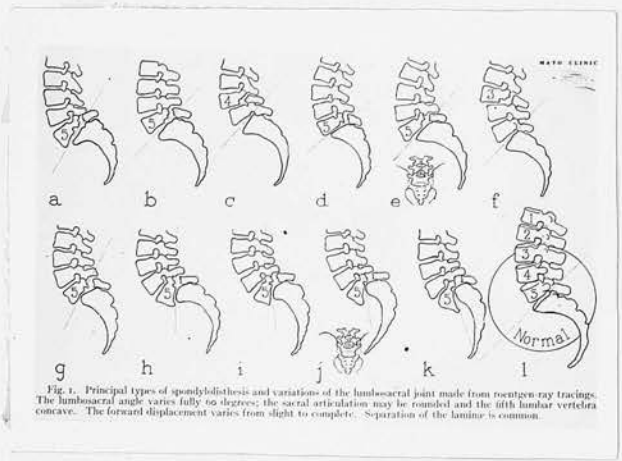


Fig. 1. Principal types of spondylolisthesis and variations of the lumbosacral joint made from roentgen-ray tracings. The lumbosacral angle varies fully 60 degrees; the sacral articulation may be rounded and the fifth lumbar vertebra concave. The forward displacement varies from slight to complete. Separation of the lamina is common.

Fig. 33.

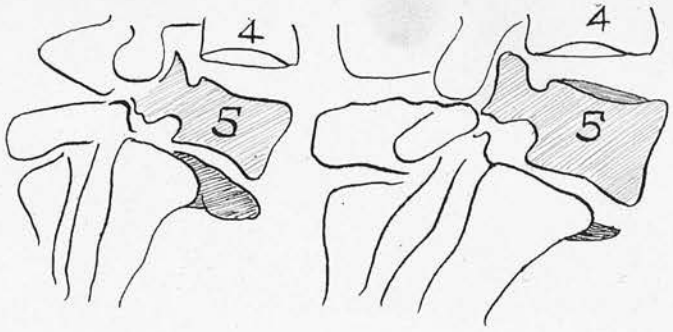
Various degrees of spondylolisthesis.

in the division of the 5th lumbar vertebra into two parts, the anterior part composed of the body - transverse processes, superior articular processes and mamillary process - is separated by solution of bony continuity from the posterior part, which is merely the spinous process and the inferior articular processes. In spondylolisthesis this portion usually remains in place while the anterior portion glides forward on the sacrum, but it has been observed in a few cases to move backwards.

The rest of the vertebral column, of course, slips forward along with the body of the 5th lumbar vertebra. There are varying degrees of spondylolisthesis from a slight slip forward of the body of the 5th lumbar vertebra to a complete displacement through 90°. In some cases the process is slow, and the pedicles of the 5th and sometimes the 3rd and 4th lumbar vertebrae grow progressively longer.

A series of X-rays shows that the 5th lumbar vertebra remains in the same plane as the sacral surface, till the forward displacement is too great to bear the weight of the whole column; only then does it fall over the edge of the sacrum on to the anterior surface of the latter.

In a young patient it may become moulded there



Tracings of two cases of spondylolisthesis showing buttress formation Aflē Capener.

Fig. 34.

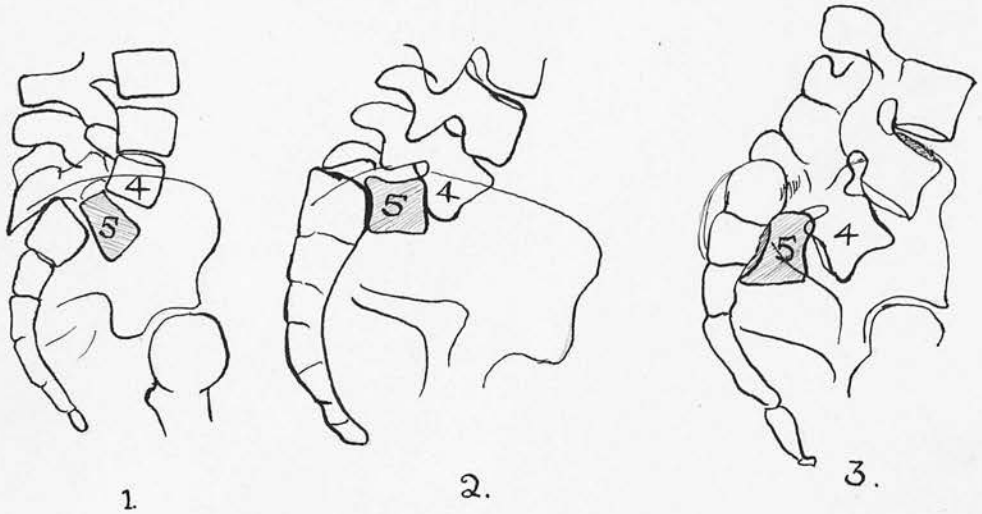


Fig. 35.

Three degrees of displacement in Spondylolisthetic patients. after Brailsford.

and then externally there is a distinct settling down or shortening of the height of the patient.

Most frequently, however, there is a semi-rotation and the displaced body comes to rest in the same horizontal plane as the sacrum. 'Buttressing' occurs on the anterior surface of the sacrum and so prevents further displacement.

It has already been mentioned that the ilio-lumbar ligaments from the transverse processes of the 5th lumbar vertebra to the iliac crests and the inter-spinous ligaments and posterior spinal muscles also assist in preventing the occurrence of spondylolisthesis.

Kleinberg[18] says "The forward inclination of the 5th lumbar vertebra has been assumed to be weak in its relationship with the sacrum. In a lateral view one gets the impression that the 5th lumbar vertebra is ready to slip off the sacrum. The lumbar articular processes placed in the sagittal plane favour dislocation".

He firmly believes in the congenital theory, in that there is some faulty development in the lumbo-sacral region, affecting particularly the ligamentous structures.

Herrgott[9], on the other hand, believes that trauma injures the weak spot in the vertebra and then secondary

inflammatory changes produce a solution of bony continuity and the normal shearing strain at that part causes the spondylolisthesis.

Vertebral caries has been quoted as a possible cause, but this brings a primary disease forward as the causal factor for the slipping forward of the body of the 5th lumbar vertebra, whereas it appears to be more generally accepted now that the primary defect is necessarily congenital.

Primary hydrorrhachis, according to Lambl[15], a teacher of Neugebauer, is the most important etiological factor. He definitely is opposed to his pupil's ideas on the subject and says that traces of hydrorrhachis can be found in all specimens of spondylolisthesis.

Brackett[20] points out the inherent weakness in the 5th lumbar laminae and says that when the erect posture is gained and the lumbo-sacral angle increased, the lumbo-sacral joint is weakened.

The weakness in the neural arch may be due to non-union of the epiphyses or a cartilaginous union, and in these cases pre-spondylolisthesis is present and a strain or blow is all that is required to precipitate a spondylolisthesis.

Von-Lackum[21], in a treatise on the mechanics of

the lumbo-sacral region, states that the lumbo-sacral joint is unstable because it is the union of a mobile and immobile spine.

The change from the four legged position to the erect posture puts an additional strain on the lumbo-sacral joint which is not provided with the joint stabilization necessary for the new position.

It is well known that there is a continuous shearing strain in the lumbo-sacral region whatever the position of the body and that if there is any weakness in the bone here, this strain will cause a solution of continuity.

In twenty-three cases reported by Hibbs and Swift, after operating they found there was a uniform separation of the laminae of the 5th lumbar vertebra from its pedicles dorsal to the superior articular facets, and there was therefore no means of anchoring the body of the 5th lumbar vertebra to its spinous process and thus preventing it from slipping forward.

These observers suggest an operation which fuses the 3rd, 4th and 5th lumbar vertebrae and the sacrum to stabilize the spine.

According to Junghanns[22], there is normally no epiphyseal line between the superior and inferior articular processes. This, however, is contrary to

the most recent observers, who state that there are frequently two primary centres of ossification in the neural arch.

Chandler[23], in his paper on lesions of the 'isthmus' of the laminae of the lumbar vertebra, says that "Of all the factors involved in the production of spondylolisthesis the solution of bony continuity of the interarticular area of the lamina is probably the most important". Of that there is little doubt, and this view has been generally accepted, except by Lane who does not attribute the lack of continuity to a congenital condition - the lack of fusion between the two primary centres of ossification in the neural arch - but to "excavation of the bone by rotation of the last lumbar on the sacrum". 3.8% of skeletons examined by Chandler show a separation of the vertebra of the 5th lumbar into two parts, with no callus formation and no signs of fracture with non-union.

The name 'isthmus' was given to the narrow part of bone between the superior and inferior articular processes. It is the narrowest part of the neural arch, in cross section only measuring $^{1}/_{2}$ - $^{2}/_{3}$ of the corresponding section of the pedicle on the posterior part of the lamina. In the upright position tremendous shearing strain is put on the isthmus and it has

to withstand this strain without much assistance of soft structures. Sudden severe strain, therefore, might easily cause solution of continuity of this part, before the shock is taken by the musculature.

This is in the normal intact isthmus. If this is weakened by non-union or cartilaginous union it is obvious that solution will occur very much more easily. Willis states that he has found embryological confirmation of the presence of congenital clefts in the region of the isthmus in a study of foetal spines.

Willis[11], in several sections of foetal spines, found areas of incomplete ossification entirely replacing the cartilage at the isthmus, leaving a vulnerable and weak spot which would readily give way under strain or trauma, being more rigid than the adjacent cartilage. Chandler[23] did not find this peculiar to the 5th lumbar vertebra. It is the natural state in all vertebrae, so he was unable to explain why it so frequently occurred at the 5th lumbar vertebra.

Fracture in childhood was suggested, but if this were the case it would be more of the nature of a greenstick fracture since the bone is unfused and more cartilaginous in consistency than adult bone.

Le Double[17] points out that instead of a space

of 1-2 mm., which one would expect to find between the two portions of bone in a spondylolisthetic vertebra, actually there is frequently a production of bone in front of and behind the split. He suggests that in the interarticular lengthening, the bony solution has occurred either without rupture of the periosteum and has remained subperiosteal, or that the case is complicated by a periosteal tear. He attributes the presence of osteophytes frequently found at the fissure to a reaction in the fibrous peripheral tracts or the fibrous ligaments with the deposit of calcareous salts. He suggests seven causes.-

(1) A foetal dropsy of the spinal canal (hydrorrhachis) (Ritgen).

(2) A supernumerary vertebra causing deviation of the vertebral column by acting like a wedge and throwing it forward (Lambl[15]).

(3) Fracture caused by trauma (Howship, Otto, Behrend, Meyer[24], Czaussow).

(4) Fracture resulting from an alteration of the bony substance due to some local or general disease (Strasser[25], Krukenberg[26], Kroenig).

(5) To a static deformity of the normal vertebrae from physiological strain (Arbuthnot Lane[3], Neold).

(6) Faulty ossification (Neugebauer[4], Farabeuf).

(7) To atavism (Poicier).

This list of possible causes includes the opinions held by all the leading authorities on

spondylolisthesis, but one might rule out hydrorrhachis as a cause - for its great rarity and also because it has always, up to date, been found to affect several vertebrae and not only the 4th or 5th lumbar. A gaping of the vertebral arcs is always present in more than one vertebra.

After the examination of only five spondylolisthetic pelvises, Lambl[15] has declared that in each case a supernumerary vertebra had caused the deformity by its wedge action.

Several observers, including Olshausen, Treub and others, have confirmed this opinion, but Herrgott says, "We should not have spoken of this (Lambl's) work which defends a theory which seems to us to merit only to be forgotten, if, in consideration of the important documents searched, one did not find it always mentioned. There is good cause to imagine that the hypothesis of Lambl will soon be forgotten. Opinionum commenta delet dics." ?

So much for Lambl's theory.

The theory of fracture as a possible cause gives rise to much discussion, but one can only point out that from all statistics on fractures of vertebrae it seems most unlikely and hardly bears consideration.

Gurlt examined 278 cases of fractured vertebrae,

and did not find a single one where the last lumbar vertebra had been affected. Usually (144 out of 278) several vertebrae were broken at the same time, mainly in the dorso-lumbar region, and usually it was the 12th dorsal and 1st lumbar vertebrae which suffered.

He goes on to point out that the transverse and articular processes are rarely broken alone and that traumatic solutions of continuity of the vertebrae are habitually complicated by luxations.

Follin has reported cases of fracture of the 4th and 5th lumbar vertebrae, but they are admittedly rare. Other cases of this nature have also been reported by Mayer[27], Otto, Rothe, Bieganski and others. There is no doubt that a slipping forward of the vertebral column with the body of the 5th lumbar vertebra on the sacrum, after a fracture causing solution of bony continuity in the pars interarticularis, can occur, theoretically at any rate, but in a healthy and normally developed individual spondylolisthesis to any degree should be prevented by the formation of callus. In old subjects non-union of the fracture at this part can and has caused spondylolisthesis, but it is extremely rare as a cause.

Krukenberg[26] is not an upholder of this theory.

If a fracture occurs there, he says that there must have been a rarefaction of the bony substance primarily, and that the fracture is only a secondary cause.

Strasser[25], in 1882, reported a case of spondylolisthesis where the isthmus was the seat of arthritic changes. Neugebauer[4] admitted this as a possible cause for the rarefaction of bone.

Kroenig suggested a tabetic affection of the bone as a primary cause. He had examined three cases of interarticular fracture of the 5th lumbar vertebral arc in tabetic patients. This, however, must be rare as a cause of spondylolisthesis.

One cannot agree with Arbuthnot Lane[3] when he says that spondylolisthesis is the normal condition in coal-heavers. According to him, in a perfectly normal, healthy individual, the continued pressure exerted on the 4th pars interarticularis by hard labour in a position where the lumbo-sacral lordosis was increased, would cause a rupture and elongation of this part.

The anterior half of the 5th lumbar vertebra begins to be pushed forward as soon as the infant gets on to its legs, but this has not been proved anatomically in dissecting rooms or in X-ray examination to be the cause of spondylolisthesis.

Moela is another observer who agrees with the Lane theory, but it seems hardly possible that prolonged and repeated pressure, however great, could cause this deformity in a healthy person.

Neugebauer[4], however, is the originator of the now generally accepted theory of the two primary centres of ossification in the neural arches. This has already been fully discussed under the section on embryology. In 1885 Professor Farabeuf demonstrated it with lantern slides to the Societé de Chirurgie of Paris. Rambaud, Renault[7] and Schavegal also believe that "each vertebral semi-arc is preceded by two points of ossification".

Von Lambertz has proved radiologically that there are sometimes four primary centres of ossification for the laminae-pedicles, transverse and articular process of the 5th lumbar vertebra, two on each side - instead of one, as in most vertebrae.

Le Double[17], when a student, examined the embryos of three humans, three dogs and three sheep, and found that in dogs and humans the centrumis preceded by one centre of ossification and the archby two, one at the right and one at the left, and in sheep the centrumby one and the archby two, as before, with an additional centre for the spinous process. This 4th centre

forms at the same time as the other two and is apparently necessary for the great development of these vertebral spinous processes.

This abnormal development of the vertebra seems the most probable primary cause of spondylolisthesis but should hardly be called "faulty" (Le Double), since it is found to be the normal state of development in many cases. This writer raises one objection to the theory.- "If it is true that the ossification of each half of the body of the 5th lumbar vertebra is effected without exception by means of two centres of ossification, these two centres unite together a long time before the union of each half with the centre and the union of the halves with each other. If it were a question of simple arrest of development one ought to find in every case of spondylolisthesis absence of fusion posteriorly between each of them and the centre. This is not the case; they are always fused posteriorly and united anteriorly with the centre.

Also to explain the post-natal persistence of the opening to right and left of the arc of the 5th lumbar vertebra one is obliged to appeal to the unknown force - atavism. In various mammals, including cetaceans, the neural arch in the fully developed state is indeed composed of two parts.

The effect of pregnancy on spondylolisthesis and the effect of spondylolisthesis on pregnancy was the first means of calling the attention of obstetricians to the condition. The increased vascularity, laxness of the pelvic ligaments and the weight of the pregnant uterus may hasten a slipping forward of the vertebra, but one does not think it possible that in a previously healthy and normal spine such a physiological event could cause a pathological condition of the vertebral column.

Spondylolisthesis materially renders labour more difficult by reducing the pelvic diameters, but in one case of a pregnant woman who had a very marked slipping of the 5th lumbar vertebra, there was no complaint whatever of low back pain or anything connected with the spine condition. The increased lordosis in the pregnant woman may initiate the slipping, provided there is already a pre-spondylolisthesis, but increased lordosis cannot be the cause of the condition since it is absent in the majority of cases.

The commonest types of injury spondylolisthetic patients complain of are.-

(1) lifting heavy weights;

(2) falls on to the buttocks;

(3) fall of weight on to the back.

It is interesting to note that an increased lordosis does not occur in any of these.

In the lifting of heavy weights, the lumbar spine is arched back and the hips are flexed; then the hips are extended and the sacrum tilts back and is forced against the 4th lumbar vertebral laminae.

In a fall on to the buttocks the lumbar curve is obliterated.

In a sudden weight falling on the back, the spine caves forwards with the lumbar portion in extreme flexion.

These injuries have been the cause apparent in spondylolisthetic men, previously with normal healthy spines, who show no exaggerated lordosis.

Capener[28] was impressed by the absence of any marked lordosis in a series of young adults with a very slight slipping. In late cases the lordosis is believed to be secondary to the displacement of the lumbo-sacral joint, and is more of a superficialization of the sacrum, which has rotated into the vertical position carrying with it the spinous process of the 5th lumbar vertebra.

Of all the possible and probable causes of spondylolisthesis one is inclined to believe in a primary congenital non-union or abnormality in the neural arches, with a secondary causal factor in trauma.

There is no doubt that trauma plays a large part in the production of the slipping, but the congenital osseous defect is the sine qua non.

What probably happens in these cases of two primary centres for each neural arch, is that the centres fuse about the tenth year, but before that time there is a weak union at the isthmus. If any severe strain or even the gradual increase in the weight of the child is put on this weak part, there is no reason why the condition of slipped epiphysis - analogous to that occasionally found with the hip joint - should not occur. There may not be a complete solution of the bony tissue, but only a stretching of the cartilage, but in either case severe trauma in that region would precipitate a spondylolisthesis.

CLINICAL SIGNS and SYMPTOMS.

Advanced cases of spondylolisthesis may produce no symptoms at all, whereas a very slight degree of forward displacement has caused great pain and discomfort to the patient.

Low back pain is the general complaint, sometimes with a previous history of trauma to the back, but frequently without. Accompanying the pain there may be stiffness of the lumbar spine with pain radiating down the back of both thighs.

Nerve disturbances are mentioned by Le Double[17] but are not very common.

Brackett[20] puts the pain down to strain throughout the ligaments in the lumbo-sacral region.

The pain is aggravated by walking any distance, by movement of the spine either sideways or forwards, and is considerably relieved by rest. It is more of a dull ache than an acute pain.

Few patients remark on the shortening in height or the crease round the body between the iliac crests and the ribs, but these signs are often well pronounced in severe cases.

The onset of the condition generally occurs after puberty, according to Henry Turner and Nikolas

Fig. 2. Limited forward bending; depression and lordosis of the spinal column, with prominence of the fifth umbar vertebra spinous process and sacrum in an adult patient with spondylolisthesis.

Fig. 36.

Photograph showing the deep furrow over the lumbar vertebrae.

Tchirkin[16], and is frequently first recognised in women in connection with parturution. In severe cases there may be pelvis obtecta - complete narrowing of the pelvic inlet - due to the displaced vertebral body felt projecting above the sacral promontory.

A deep furrow over the vertebral column, starting above the projection formed by the 5th lumbar vertebral spinous process, can be seen passing up and ending at the spine of the 1st lumbar vertebra, which can be felt as a slight projection. This is known as Tchirkin's sign and is found most usually in cases which also have the horizontal crease mentioned above. There is thus a slight kyphosis at the lumbo-dorsal junction. On deep abdominal palpation - after emptying the bowel by means of purgatives and enemata - the protrusion formed by the body of the 5th lumbar vertebra can sometimes be felt. Below this projection the fingers slip into the pelvis.

Tchirkin's Sign, described by him[16].-

"The presence of this sign is due to the accommodation of the spine to the sudden change in contour and as a compensation for the static deformity produced by the forward dislocation and tilting of the 5th lumbar vertebral body..... The body is thrown

Fig. 621.—Spondylolisthetic Pelvis. Shows the hump of last lumbar spine.

Fig. 37.

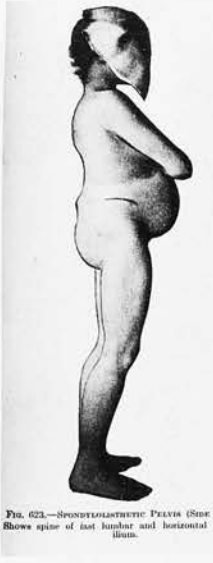


Fig. 623.—Spondylolisthetic Pelvis (Side View). Shows spine of last lumbar and horizontal crest of ilium.

Fig. 38.

Fig. 289.—A patient with severe spondylolisthesis, showing characteristic rotation of the pelvis upon a transverse axis.

Fig. 39.

Photographs of cases of spondylolisthesis.

back to maintain the position of the centre of gravity and a lordotic curve is produced. This lordosis is associated with a compensatory forward bend of the spine in the region between the flexible lumbar and rigid dorsal vertebrae. This is seen as a slight kyphosis at the dorso-lumbar junction - a prominence of the 1st lumbar vertebra spinous processes.

Another sign - of importance to obstetricians - is that described by Michaele. The rhomboid, or lozenge, is more flattened from above downwards in cases where spondylolisthesis is present. It is formed by the medial borders of the gluteus maximus which meet with the mid-line distally and the upper borders of the rhomboid are formed by lines joining the lateral depression to that usually present over the 5th lumbar vertebral spine. The essential measurements of the rhomboid are the distances between the posterior superior iliac spines, and the vertical distances from the midpoint of the line joining these two points to the 5th lumbar spine. The average of the former is 4", of the latter $1\frac{1}{2}$" - $1\frac{3}{4}$". In spondylolisthesis the median depression which marks the 5th lumbar vertebra in the normal, is absent.

Spondylolisthetic patients also walk with a slight waddle, described by Lockhart as resembling

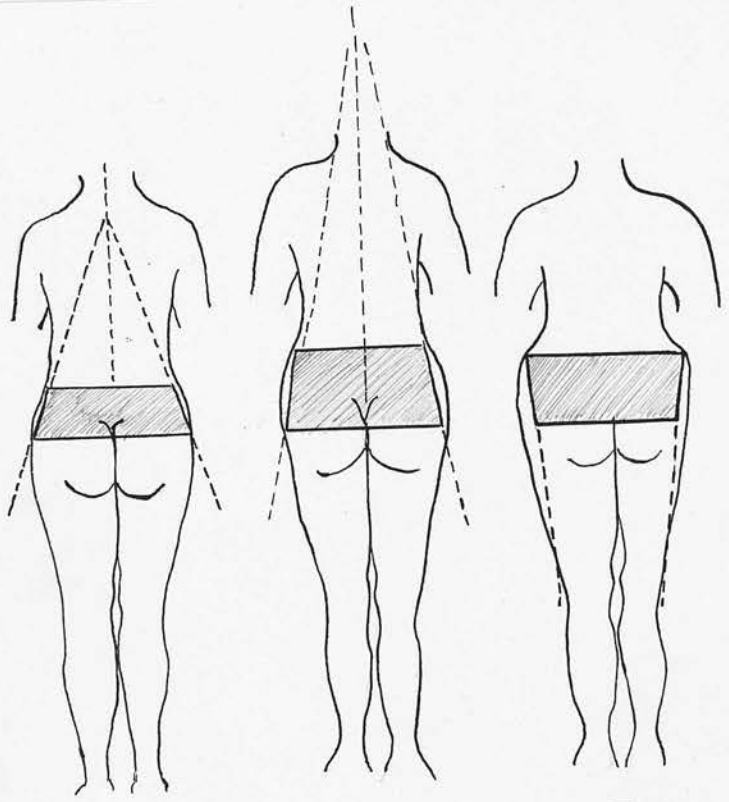
that of a quadruped. It is also known as the "duck's gait".

The prominent sacrum can be seen and easily felt with the projecting spinous process of the 5th lumbar vertebra above it. A distinct angle is noticed above this spine, and so differs from what might be mistaken as an increased lordosis. The latter is a curve and the former a definite angle. The hollow above this projection is formed by the mobile spinous process of the 5th lumbar vertebra being displaced upwards.

Obstetrically, the antero-posterior diameter of the inlet (or conjugate) of the pelvis is diminished and the promontary of the sacrum appears to project downwards and forwards. This is of course the slipping vertebral body which can be felt per vaginam.

Many patients have tenderness on palpation over the lumbo-sacral joints, and some experience difficulty in fully extending the hip joints.

According to Le Double[17], the shortening of the trunk in spondylolisthesis is due to the sinking of the vertebral column into the pelvis. This makes the iliac crest appear to rise, whereas in congenital luxation the shortening is due to the descent of the pelvis. The latter condition exaggerates the bi-trochanteric diameter in relation to the bisiliac,



1. Congenital luxation.
2. Normal.
3. Spondylolisthesis.

Bi-iliac-bi-trochanteric trapeze.

Fig. 40.

which is lessened.

In spondylolisthesis, on the other hand, the bisiliac diameter, normally the smaller, becomes larger and the trapeze differs in shape from the normal.

X-RAY.

Without an X-ray examination of the patient it is impossible to clinch the diagnosis of spondylolisthesis but with the aid of an antero-posterior view and, more particularly, a lateral, the condition is obvious.

Antero-posterior.-

The characteristic feature with this view is the bow-like outline formed by the border of the transverse processes and the anterior convex border of the body of the 5th lumbar vertebra. The shadow is seen projected on to that of the sacrum, when seen from above downwards. This line is present in slight cases when the body is only projecting a very short distance, and no other known condition - except of course a dislocation of the same vertebra - can produce it.

Ossification of the anterior common ligaments may be mistaken for this condition but the X-ray shadow so produced should not be confused with that of spondylolisthesis by any experienced radiographist.

The neural arch appears to be directed proximally but this is also found to be the case in patients with an exaggerated lordosis.

Further, the sacrum is pushed backward and

Normal Spine. Spondylolisthesis.

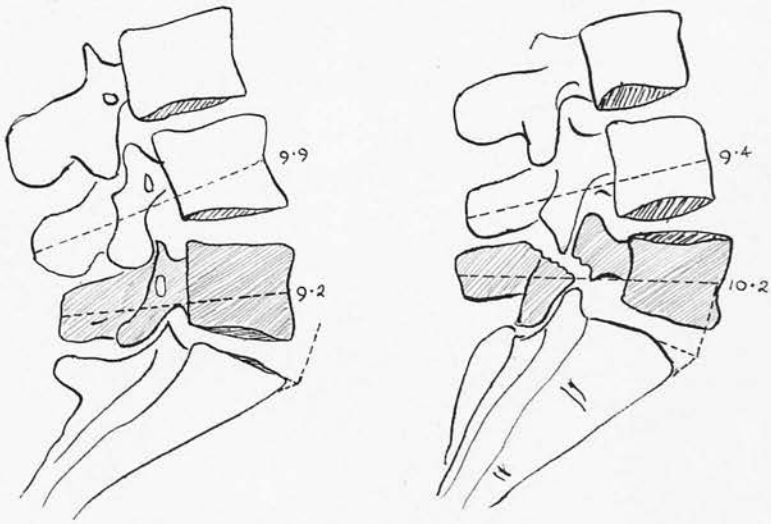


Fig. 41.

Two tests for early spondylolisthesis.

1. Comparison of antero-posterior diameters of 4th & 5th Lumbar vertebræ.

2. Ullman's Sign. In the normal spine, a line drawn at right angles to the superior surface of the sacrum, lies in front of the body of the 5th L.V., but in Spondylolisthesis it passes through the tip of the body

After Copener.

superficialized, while the border of the sacro-iliac joints are almost vertical and there is little overlapping (Brailsford[5]).

Laterally.-

The main difficulty in interpreting a lateral X-ray photograph lies in the fact that the other pelvic bones become superimposed on those of the bodies of the 5th lumbar vertebra and the 1st sacral vertebra.

If a line is drawn connecting the anterior surfaces of the lumbo-sacral vertebrae, a curve is formed with the convexity depending on the lumbo-sacral angle. If the body of the 5th lumbar vertebra has slipped forward, there is a definite break in the continuity of the curve.

Secondly, if a straight line is drawn along the anterior border of the 1st sacral vertebral body, it will project upwards and to the front of the 5th lumbar vertebra unless this is displaced forwards, as in spondylolisthesis. Then the line will be cut by the body of the last lumbar vertebra. This is known as Ullman's sign.

It has been suggested that one can diagnose the presence of spondylolisthesis by measuring the antero-posterior length of the 5th lumbar vertebra, but this is not at all satisfactory as the spinous processes

have been found to vary in length in different individuals. Köhler has recorded a case with a spinous process of 5 cms. long.

In some cases an increased density and compression of the neural arches and spinous processes of the 5th lumbar vertebra is seen - suggestive of osteochondritis. The spinous process of the 5th lumbar vertebra in these cases appears to be moulded on to the superior surface of the 1st sacral body.

In a lateral X-ray photograph, the degree of slipping can be easily made out and is really better for the early diagnosis of the condition than the antero-posterior view.

The points to look for on examination of the X-ray plate are.-

(1) The alignment of the anterior and posterior borders of the vertebral bodies.

(2) The width of the intervertebral disc.

(3) The shape of the intervertebral foramina.

(4) The continuity of the neural arches.

(5) The length and relation of the spinous processes.

(6) Evidence of bone change.

(7) The lumbo-sacral angle and the degree of the curve.

(8) Evidence of spontaneous arrest, such as buttressing.

In early cases, spondylolisthesis is not so easily seen owing to the thickness of the intervertebral discs. The intervertebral space may be narrowed, probably secondary to the displacement.

The intervertebral foramina are elongated antero-posteriorly in spondylolisthesis.

According to Capener[28], the most characteristic feature is the break in continuity in the laminae, a gap appearing to continue the lumbo-sacral intervertebral space backwards, above the spinous process of the 5th lumbar vertebra.

Normally, the 5th lumbar vertebral spinous process is the shortest of all the lumbar spinous processes, but in fracture dislocation it projects backwards beyond the space of the 4th. This also occurs in spondylolisthesis whatever the cause.

Bony buttresses may cause spontaneous arrest of the slipping, the inferior surface of the 5th lumbar vertebral body resting on the buttress and the inferior articular process of the 4th lumbar vertebra may tend to rest on the sacrum.

TREATMENT.

There are several possible methods of treatment open to the surgeon, according to the degree of the displacement. Case IV, for instance, has no pain or discomfort although she is a very advanced degree of spondylolisthesis, and it would not be justifiable to encumber a woman with a young family engaged in heavy household duties with a supporting frame, in the hope of preventing any further slipping of her 5th lumbar vertebra. From the X-ray appearance in this case, it is most probable that some bony ankylosis has occurred between the base of the 5th lumbar vertebra and the anterior surface of the sacrum and that no further slipping will occur. It will be interesting to study X-rays in a few years' time, to see if any further degree of spondylolisthesis is present.

The various methods of treatment are as follows.-

(1) Manipulative.

It is difficult to imagine how manipulation of the spine could possibly replace the 5th lumbar vertebra if it had slipped very far off the sacrum. Increasing the lordosis of the spine would tend to

increase the displacement, while flexion would not have any effect in reducing the length of the inter-articular 'isthmus', or replacing the slipped vertebra.

(2) Conservative Methods.

These can be employed where the patient refuses operation or if the condition is too far advanced for any operative assistance. A man, aged 22, with severe pain in the lumbo-sacral region, showed decreased mobility of the lumbar spine and, on X-ray examination, an advanced degree of spondylolisthesis with a possible fracture of the 5th lumbar vertebra also, so it was decided that operative interference was not justifiable and a supporting jacket fitting round the pelvis, with supporting bars going up the back and another band under the axilla, thus raising the whole spine, was fitted. This proved most comfortable and eased the pain considerably and the patient preferred it to any operation.

Poroplastic jackets have been used after spinal operations and give a sense of security to the patient when he gets out of the posterior plaster shell. They do not act so much as a support to the back as a splint to the spine and prevent the patient flexing or extending the lumbar spine after a graft or ankylosing

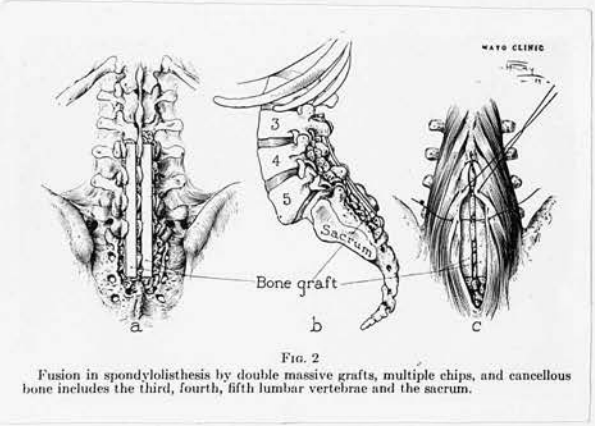


FIG. 2
Fusion in spondylolisthesis by double massive grafts, multiple chips, and cancellous bone includes the third, fourth, fifth lumbar vertebrae and the sacrum.

Fig. 42.

Steps in the bone-graft operation as performed by Albee.

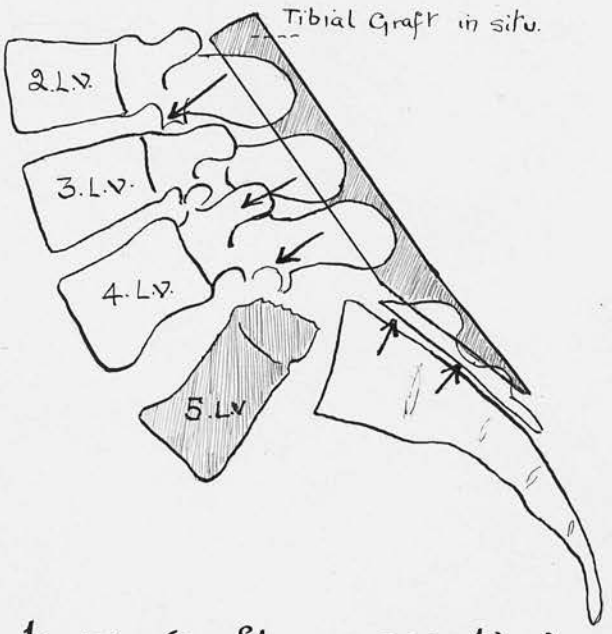
operation. Henry Meyerding (Mayo Clinic) combined manipulative and conservative methods. Traction was applied to the patient on a firm mattress, with the legs in a double spica cast, then later a well fitting poroplastic jacket was worn. Unless prolonged for many months, this method can give little hope of permanently easing the pain, or relieving the patient in any way. Temporarily, the recumbent position in plaster relieves the pain, but when the patient gets up and starts walking again, the weight and movements of the body must inevitably bring on the previous symptoms.

(3) Operative Methods.

These produce the best results in the end, but there is the usual risk accompanying all surgical interference and many patients entertain the gravest suspicion and fear of the surgeon's knife.

(A) Albee's or Hibbs' Arthrodesis. These surgeons ankylosed the 3rd, 4th and 5th lumbar vertebrae and 1st and 2nd sacral vertebrae by a double bone graft fitted to the sides of the denuded spinous processes and sacrum.

Using an incision curved slightly laterally, the lower lumbar spine and the proximal part of the sacrum



Tibial bone graft preventing forward sagging of spine by fusion with lumbar spines and sacrum.
Arrows indicate the direction of forces exerted on the graft.

After Albee.

Fig. 43.

was exposed. The laminae were bared and multiple chips and cancellous bone packed between them and the spinous processes of the vertebrae. Massive grafts were held in place against the freshened sides of the spinous processes by chromic cat-gut. These were taken from the tibia and measured before cutting with the circular saw, so that they were the same size as the area exposed. The wound was closed without drainage and, after six weeks in a posterior shell, the patient was allowed up in a poroplastic jacket or brace.

In Case II, a single Albee graft was used to arthrodese the lumbar spine, but while the patient was being nursed he sneezed and the sudden jerk made the graft snap in two. Fortunately the break occurred above the level of the 5th lumbar vertebra, so the operation was not entirely wasted. In this patient's case, the application of the graft did not relieve the symptoms to any great extent and therefore a further operation was considered.

The bone graft did not directly prevent the body of the 5th lumbar vertebra slipping further, but by preventing the other lumbar vertebra from moving, in relation to the sacrum, it indirectly prevented the continuance of spondylolisthesis.

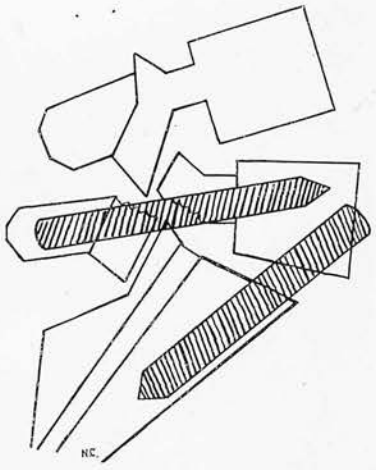


FIG. 295.—Theoretical alternatives to the posterior bone-graft operation for spondylolisthesis.

Fig. 44.

From the diagram it is well shown that the single or double graft is the site of a severe cross strain, and therefore liable to break at any strain or trauma.

(B) As an alternative method of arthrodesis, two bone pegs can be used, one to ankylose the body of the 5th lumbar vertebra to the sacrum, the other to join the anterior and posterior halves of the 5th lumbar vertebra. In theory this is excellent but in practice impossible as the pegs would have to pass through the cauda equina.

(C) In Case I a bone peg was driven into the 5th lumbar vertebra body to ankylose it to the sacrum. This was done by the abdominal route as described in the case report and proved highly satisfactory.

Whether the bone peg would be absorbed in time was considered as a possibility, so on the next cases (Cases II and III) another method of arthrodesis was used.

(D) Anterior Intra-articular Arthrodesis. The operation has already been described in detail, so it will suffice merely to mention it. An iliac bone wedge was removed and hammered firmly into place between the bared surfaces of the 5th lumbar vertebra and the sacrum. This prevented the body of the last

lumbar vertebra from slipping any further off the sacrum but did not in any way incapacitate the patient in his work. Lumbar movement eventually would be almost perfect and the pain greatly, if not completely, relieved.

In Case III the bone wedge was suddenly displaced while the patient was being placed in his posterior shell, so when Case II was being operated upon he lay in his posterior shell during the operation and the wedge was nailed into position by a nail into the sacrum through the wedge. This ensured its staying in position.

Of all these methods, the last described obviously seems the most effective, both in theory and in practice.

CONCLUSIONS.

1. That spondylolisthesis occurrs equally in males and females.

2. That it is due primarily to a congenital abnormality in the appearance of five centres of ossification of the vertebra instead of the usual three, and that trauma on such an abnormality will precipitate the condition.

3. That an advanced degree of spondylolisthesis can be present in an individual without causing any disturbing symptoms - in fact without that individual knowing that there was any abnormality of his spine present; and that a very slight slipping can cause severe pain and discomfort.

4. That the presence of such a condition impairs the stability and strength of the lumbo-sacral joint, and also causes difficulty in childbirth by reducing the diameter of the pelvic outlet.

5. That the characteristic bow-like outline of the 5th lumbar vertebra on antero-posterior radiography, projected against the shadow of the flat

sacrum is pathognomonic.

6. That treatment should aim at arthrodesing the body of the 5th lumbar vertebra to the sacrum, rather than ankylosing the spinous processes of the lumbar and sacral vertebrae. Cure cannot be effected but further displacement can be prevented by efficient surgical treatment.

REFERENCES.

1. Kilian. de Spondylolisthesis Gravissimae. Bonnae, 1854.

2. Albee. (Bone & Joint Surg., July 1927, IX, 427.)Rev. Assoc. Méd. Mex., Dec.1928, VII, 9. (Radiology, Oct. 1928, XI, 340.

3. Arbuthnot Lane. Trans. Path. Soc. Lond., 1885, XXXVI, 364.

4. Neugebauer. New Sydenham Soc. Monograph, London, 1888, CXXI.

   Spondylolisthesis et Spondylézème, Paris, 1882.

5. Brailsford. Brit. Journ. of Surg., 1929, XVI, 562.

   Brit. Journ. of Radiol., 1933, VI, 666.

6. Meyerding. Surg. Gynec. & Obst., 1932, LIV, 371.

7. Rambaud & Renault. ibid. 233.

8. Lovett. Trans. Amer. Orthop. Assoc., 1897, X, 20.

9. Herrgott. Ann. de Gynécol., 1883, IX, 321.

10. Magnuson. Internat. Clinics, Series 30, 1920, IV, 181.

11. Willis. Journ. of Bone & Joint Surg., No. 4, 1931, XIII, 709.

12. Hey Groves. Med. Annual, 1927, 52.

13. Kleinberg. (Internat. Clinic, Sept.1933, III, 216.)Arch. Surg., Sept. 1933, XXVII, 565. (Bone & Joint. Surg. April 1934, XVI, 441.

14. Henry. Minnesota Med. St. Paul, 1926, IX, 37.

15. Lambl. Zeitsch. f. Gynaek., 1885.

16. Tchirkin. Journ. Bone & Joint Surg., 1925, VII, 763.

17. Le Double. Traité des variations des os de la Colonne vertébrale. Gaz. méd. du Centre, 1912, XVII, 29.

18. Whitman. Journ. Bone & Joint Surg., 1924, VI, 808.

19. Lange. Zeitschr. f. Orth. Chir. 1911, XXIX, 544.

20. Brackett. Journ. Amer. Med. Assoc., 1924, LXXXIII, 1068.

21. Von Lackum. Journ. Amer. Med. Assoc., 1924, LXXXII, 1109.

22. Junghanns. Fortschr. a. d. Geb. d. Röntgenstrahlen, Feb. 1930, XLI, 239.

Arch. f. Klin. Chir., 1930, 159, 423.

23. Chandler. Surg. Gynec. & Obst., Sept. 1931, LIII, 273.

24. Meyer. Rev. med. de la Suisse Rom., October 1933, LIII, 777.

Arch. f. Orthop., November 1930, XXIX, 109.

25. Strasser. Breslauer. Arzt. Zeitschr., 1882.

26. Krukenberg. Arch. f. Gynaek., 1885, XXV, 13.

27. Mayer. Ticé's Practice of Med., 1920, X, 585.

28. Capener. Brit. Journ. Surg., Jan. 1932, XIX, 374.